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Seneca Creek Watershed Management Study
Volume 1

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ABSTRACT

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The Metropolitan Washington Council of Governments (COG) is the regional organization of the Washington, D.C. area's major local governments and their governing officials. COG works towards solutions to such regional problems as energy shortages, traffic congestion, inadequate housing, air and water pollution. The Washington Metropolitan Water Resources Planning Board serves as the areawide wastewater management agency for the Washington area. The Board is involved with regional policy issues related to provision of adequate wastewater treatment, sludge disposal, nonpoint source pollution, and municipal water supplies. The Maryland-National Capital Park and Planning Commission is the bi-county agency responsible for land use planning and administration of the public park systems in Montgomery and Prince George's Counties, Md.

REPORT ABSTRACT: Using the Seneca Creek watershed in Montgomery County, Md. as a case study area, the report presents a methodology for integrating consideration of water quality impacts into the land use planning processes of local governments. Evaluates the potential impacts of future land use development options on watershed water quality, stream habitat and the Little Seneca Lake reservoir; and assesses whether these impacts can be mitigated through non-structural planning measures, urban stormwater and agricultural runoff control measures. Major elements described include stream monitoring, review of historical water quality in the watershed, development of a watershed hydrologic and water quality simulation model, detailed model applications, and cost-effective analysis. Features of an effective urban nonpoint control strategy are also discussed.

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

In accordance with a cooperative interagency agreement, the Metropolitan Washington Council of Governments (MWCOG) and M-NCPPC jointly undertook a comprehensive water quality management study in the Seneca Creek Watershed. The chief purpose of the study was to provide an example of how detailed consideration of water quality impacts can be directly integrated into land use planning processes of local governments. The project was funded as part of an EPA Nationwide Urban Runoff Program demonstration grant to COG.

Major elements of the study included:

- An intensive water quality monitoring program on Seneca Creek.
- An overall evaluation of historical water quality.
- The development of hydrologic and water quality simulation model of the Seneca watershed.
- Basin-wide model applications to evaluate the water quality/quantity impacts of future land use on the overall Seneca watershed.
- Detailed model applications to illustrate the relative water quality impacts of land use options under consideration for the Clarksburg Master Plan area (in the Little Seneca watershed).

FOCUS ON CLARKSBURG PLANNING AREA

The project placed particular emphasis on the analysis of projected water quality impacts and nonpoint pollution management options in the Clarksburg Planning Area. The Clarksburg area was selected for special attention because it included the entire upland drainage to the Little Seneca reservoir. Also, streams in the watershed provide support to one of the county's most diverse fish communities. It was felt that this study could provide relevant information on likely changes in water quality and stream habitat associated with land use options for timely incorporation into the master planning process.

Key questions examined under the Clarksburg portion of the study were:

- What potential impacts will the future development options under review by MNCPPC staff have on water quality and aquatic life habitat in the Little Seneca reservoir and its tributary streams?
- Can these impacts be mitigated to any meaningful degree?
- If so, what would be the estimated costs of preventing adverse impacts?

Comparison of Land Use Planning Alternatives

Runoff control options investigated included:

- Non structural land use planning measures emphasizing preservation of open space.

- Conventional "dry" stormwater ponds (for peak runoff control).
- "Wet" stormwater ponds for peak runoff and nonpoint source control (including extended detention designs for highly impervious land uses).
- Comprehensive agricultural best management practices (BMP's) for control of agricultural runoff.
- "Wet" ponds and agricultural BMP's.

Comparisons for each land use/runoff control combination impact were developed in terms of simulated changes in peak stream flows, dry weather flows, minimum dissolved oxygen levels, nutrient, sediment and BOD loads, stream bank erosion, channel deposition, and reservoir chlorophyll "a" levels.

Impacts of Future Development Without Runoff Controls

In the absence of stormwater and nonpoint source controls, all of the Clarksburg master plan land use options were projected to have deleterious effects on both instream habitat and lake water quality, relative to existing conditions. In particular:

- Peak stormwater runoff discharges would increase by 20 to 40 percent.
- Dry weather low flows would be reduced by 10 to 25 percent.
- Streambank erosion would dramatically increase from 40 to 116 percent.
- The number of days that tributary streams would experience high levels of turbidity would rise by 13 to 28 percent.
- Loads of sediment, nitrogen and BOD delivered to Little Seneca Lake were projected to increase by 10 to 50 percent, depending on the land use scenario.
- Phosphorus loads, generated by existing and all future land use scenarios, were projected to produce eutrophic conditions in the lake. These conditions are often characterized by blooms of nuisance algae, dissolved oxygen deficits, odor problems and reduced water clarity.

COMPARATIVE EFFECTIVENESS OF NONPOINT CONTROL STRATEGIES THE IN CLARKSBURG PLANNING AREA

Land Use Planning Alternatives

Master plan alternatives calling for more intense development typically had the most severe impacts on stream habitat. These impacts included: increased peak discharge, diminished dry weather flows, higher streambank erosion rates and longer durations of high turbidity. On the other hand, the master plan alternatives which emphasized conservation of agricultural and forest lands, and were oriented towards lower density development, experienced less adverse impacts on stream habitat.

Conversely, planning alternatives which emphasized conservation of agricultural lands were projected to deliver nutrients and sediments to the lake in quantities which approached, and in some cases exceeded, those delivered in the more intensive development scenarios. This was largely due to the fact that agricultural loadings were normally higher than those from suburban areas. This suggests the need to couple agricultural preservation efforts with control of their nonpoint source loadings.

"Dry" Pond Urban Stormwater Controls

The application of dry stormwater ponds would not prevent much of the projected deterioration of water quality and stream habitat associated with future development in the Clarksburg Planning Area. The principal purpose of these structures, flood control, would be effectively served. (i.e., peak discharges would be shaved considerably through much of the watershed.) However, under existing dry pond design criteria only minimal reductions in sediment and nutrient loads would be achieved. Also streambank erosion rates would only be marginally reduced. Similarly, no changes in dry weather low flow or duration of high stream turbidity levels were projected to occur. Finally, nutrient enrichment problems in the lake would not be noticeably diminished.

"Wet" Pond Urban Stormwater Controls

This control strategy was projected to be very effective in mitigating many of the adverse effects of future development. Peak runoff discharges were reduced to below pre-development levels (i.e., existing conditions) and dry weather low flows were moderately augmented. Uncontrolled streambank erosion rates were reduced by 25 to 40 percent. Similar or greater reductions were projected for basin wide nitrogen, phosphorus, and BOD loads delivered to the lake. Sediment loads were reduced by 15 to 35 percent. Projected algal levels in the Lake declined by 5 to 14 micrograms/liter of chlorophyll "a", suggesting a significant potential for alleviating the potential eutrophication problem in the Lake.

Agricultural Runoff Controls

This control scenario was patterned after the recently adopted SCS watershed conservation plan now in its first phases of implementation in Little Seneca. The program assumed the application of a wide variety of crop and pasture land management practices. Model projections indicated that the agricultural BMP controls were a very effective strategy in the land use scenarios where agricultural lands are retained in sizeable quantities. Most of the water quality benefits were associated with reductions in watershed nutrient, sediment and BOD loads, resulting in corresponding declines in algal and turbidity levels in the Lake.

Combined Wet Pond and Agricultural Controls

The greatest degree of protection of lake water quality and stream habitat was realized when both urban and agricultural runoff controls were implemented together. In all but the most developed scenario, combined application of both controls resulted in both enhanced water quality conditions in the lake, and significant reductions in the deterioration of stream habitat, relative to existing conditions. Specifically, projected chlorophyll "a" concentrations within the lake were typically reduced by 40 to 60 percent. Chlorophyll reductions of this magnitude would prevent development of a eutrophic condition within the Lake. Sediment, nitrogen, phosphorus and BOD loadings were reduced to levels below those likely to be experienced under current land use patterns. Also, the flow regimes of the tributary streams (peak discharges and low flows) were not projected to change much from existing conditions. Streambank erosion rates in most scenarios were moderately reduced (25 to 45 percent.)

COMPARATIVE COSTS OF CONTROL STRATEGIES

A central aspect of the study involved the determination of how much investment would be needed to carry out a particular nonpoint source control strategy in the Clarksburg Planning Area. Present worth cost estimates for construction and maintenance of urban and agricultural stormwater controls were prepared as follows:

CONTROL STRATEGY	TOTAL COST, BASIN WIDE (million dollars)	ANNUAL PAYMENT		
		Dwelling Unit	Commercial Acre	Treated Acre
DRY PONDS	$ 4.3 - 7.6	$14	236	-
WET PONDS	$ 9.4 - 14.3	$22	325	-
AG. CONTROLS	$ .07 - .66	-	-	23
COMBINED CONTROLS	$10.1 - 14.4	$22	325	23

*NOTE: Total capital and O&M amortized for twenty years at 8 percent.

Average annual residential payments for basin-wide dry and wet stormwater controls were estimated to be $14-$22 per Dwelling Unit per year. Agricultural controls were estimated to cost $23 per treated acre per year.

Cost-Effectiveness Comparisons

Cost effectiveness comparisons were made which involved a direct comparison of the total basin-wide cost of a particular land use planning/control strategy combination with its relative effectiveness (as determined by its numerical ranking in a relative water quality index). Several combinations were identified which resulted in maintenance of, or improvements to, existing water quality conditions at a reasonable cost. These alternatives typically involved land use planning measures which emphasized conservation of open space, and were oriented towards lower density land use, in conjunction with basin-wide application of wet ponds and/or agricultural controls.

Three general conclusions emerge from the cost effectiveness analysis. First, agricultural control achieve more water benefits, per dollar spent, than any other control strategy. Secondly, wet ponds produce the most water quality benefits of all control measures, but are also the most expensive. Thirdly, dry pond controls designed only to attenuate stormwater peaks confer only marginal improvements in water quality, relative to their high cost.

Benefits of Runoff Controls

Although the economic benefits of an effective control program are difficult to quantify with any precision, some of the conceivable benefits include:

- Cost savings in the form of reduced dredging and disposal costs in the forebays and main reservoir of Little Seneca Lake.
- Protection of property and human life from flooding.

- Conservation of highly productive soils (Ag. BMPs only).
- Increased efficiency of basin farming (Ag. BMPs only).
- Recreational benefits from continued maintenance of a recreational fishery in tributary streams and Little Seneca Lake.
- Aesthetic benefits achieved by reducing the stormwater impacts to the channels of tributary streams and the eutrophication potential of Little Seneca Lake.

In this study, it was only possible to assign economic value to one of those benefits-savings in sediment forebay dredging costs. Savings of $129,000 to $330,000 could be realized over twenty years if agricultural controls; wet ponds or both, were applied in the basin.

RECOMMENDATIONS

There are a diversity of possible approaches which local planners and decision-makers can implement to develop an effective stormwater and nonpoint source control program in the basin. Several general considerations, however, should be incorporated into the fabric of any watershed plan, and some of these are outlined below.

Targeting Resources

Given the fact that management resources may be scarce, a control program should be concentrated on:

1. Controlling water quality constituents which exert the greatest stress in the stream environment.
2. Applying controls to these areas which are projected to have the most severe impacts or curtail beneficial uses.

Pre-development Land Use Planning

Several measures can be taken which help to minimize the impact of development on Seneca Creek. These include cluster development conservation of open space, preservation of agricultural land, and stream valley and regional park acquisition.

Selection of Stormwater Controls With High Pollutant Removal Capability

Urban stormwater structures vary in their ability to mitigate water quality and quantity impacts. Wet stormwater ponds, extended detention dry ponds, porous pavements and infiltration controls appear to have the greatest multi-purpose potential. Design of all stormwater controls should incorporate careful planning to enhance their pollutant removal potential.

Application of Agricultural Controls

Agricultural BMPs were projected to achieve the most water quality benefit per dollar spent than any other measure. Full compliance with the current SCS Little Seneca Conservation Project is encouraged, and further application of agricultural BMPs to the remainder of the Seneca Watershed may be warranted.

Full Implementation of Controls

The projected effectiveness of the control measures examined in this study are predicated on two important factors: full application of all new development and continued maintenance over the useful life of a structure. If either condition is not met, then the effectiveness of a basin-wide control program will be seriously diminished.

Re-instituting a Water Quality Monitoring Program

Installation of water quality sampling program will be necessary to gauge the results of a basin-wide program, provide long term trend data, identify problem areas and re-verify the Seneca Creek Model. Also, it is recommended that this sampling have an additional biological aspect, including occasional analyses of trace metal levels in fish tissue. As a first priority, sampling aimed towards tracking water quality into, within, and downstream of the Little Seneca reservoir is highly recommended.

It is hoped that the information and recommendations developed under this study will provide M-NCPPC planners and other interested parties useful input with which to assess the water quality impacts of land use decisions in the Clarksburg planning area.

Chapter One
INTRODUCTION

INTRODUCTION

Situated on the fringe of the expanding Washington, D.C. metropolitan area, the Seneca Creek watershed is on the verge of major transition. It is anticipated that the watershed will undergo significant urbanization over the next twenty years, losing much of the rural agricultrual character it has maintained over the past two centuries. Changes in land usage of this nature and magnitude can be expected to induce dramatic changes in the quantity and quality of surface waters in the watershed. Local planners have sought to mitigate the adverse impacts associated with those changes through a planning process that has included consideration of needs for agricultural, stormwater and nonpoint source pollution management as part of the evaluation of land use planning alternatives. Key questions raised early in the planning process were:

- What is the nature and magnitude of potential impacts to surface water quality and quantity within the tributaries and impoundments of Seneca Creek?
- How effective would nonpoint source and stormwater management control programs be in mitigating these impacts?
- How much investment would be necessary to achieve reasonable levels of water quality?

To address these issues, the Metropolitan Washington Council of Governments (MWCOG), in cooperation with the Maryland-National Capital Parks and Planning Commission, initiated a comprehensive three year study of this urbanizing watershed. The chief purpose of the study was to provide a prototype example of how detailed consideration of water quality impacts can be directly integrated into the land use planning processes of local governments in the Washington area.

Major elements of the study included the following efforts:

- An intensive water quality monitoring program.
- The development of a hydrological and water quality simulation model to represent the key processes affecting water quality and stream habitat in the watershed.
- The application of the calibrated watershed model to evaluate the impacts of future development (as embodied in MNCPPC land use planning options) on water quality and quantity in Seneca Creek.
- Further application of the model to assess the effectiveness of selected urban and agricultural best management practices (BMP's).
- Relative comparison of levels of water quality achieved under the various BMP strategies with estimates of the level of investment required to achieve them.

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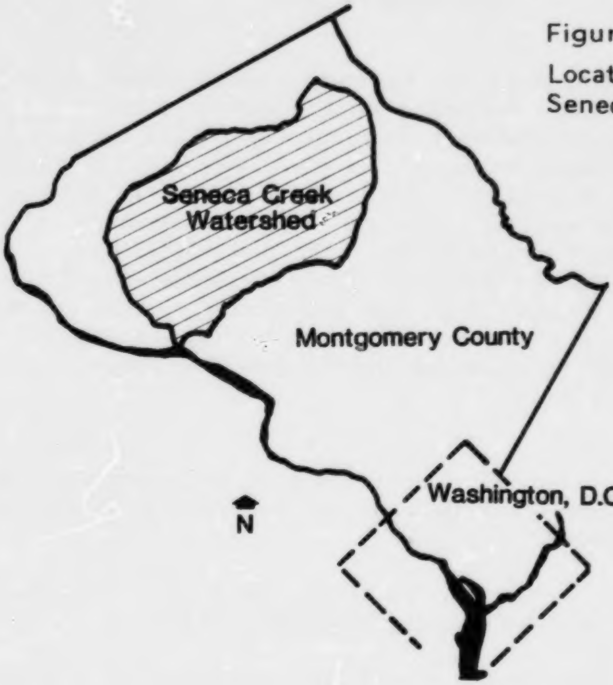
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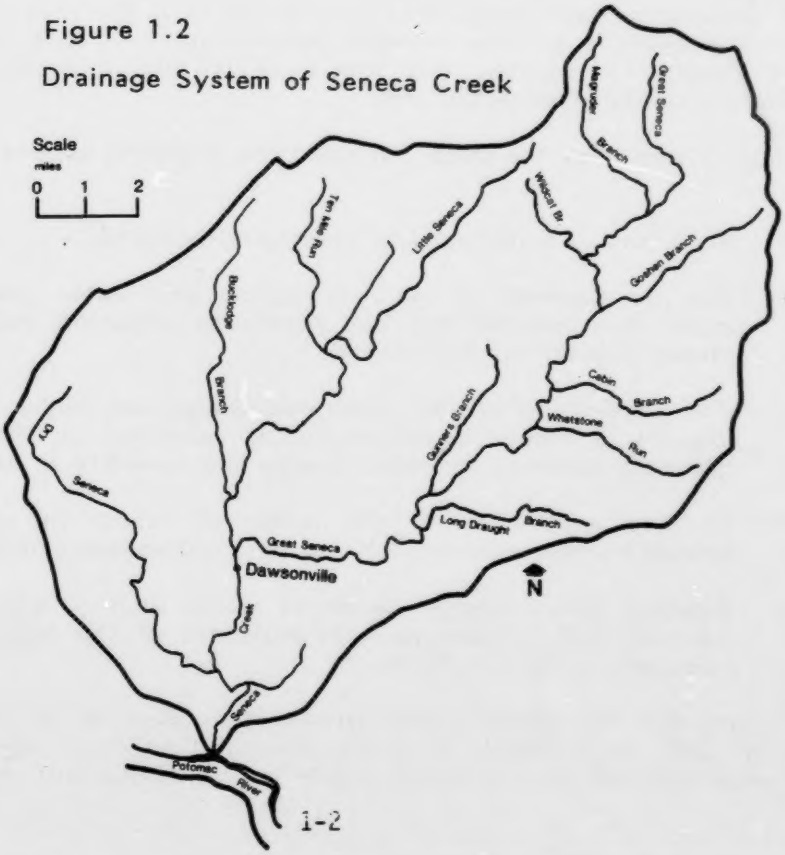
Figure 1.1

Location of the Seneca Creek Watershed


Scale
miles
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2
Magruder Branch
Great Seneca
Wildcat Br
Little Seneca
Ten Mile Run
Goshen Branch
Bucklodge Branch
Cabin Branch
Whetstone Run
Gunners Branch
Long Draught Branch
Great Seneca
Dawsonville
Dry Seneca
Creek
Seneca
Potomac River
N

Figure 1.2

Drainage System of Seneca Creek

final report on the Seneca Creek component of the overall Washington area NURP project.

Description of the Study Area

The Seneca Creek watershed is located in the western portion of Montgomery County, Md. The center of the watershed is approximately 25 miles to the northwest of downtown Washington, D.C. As shown in Figure 1.1, Seneca Creek occupies a large portion of the County. In fact, it is the largest watershed in the County and occupies approximately 128 square miles or 27 percent of the land area.

The watershed is situated on the Piedmont Plateau, and it can be characterized as having a rolling and hilly topography. Elevations range from about 200 feet above sea level near Seneca's confluence with the Potomac, to about 700 feet in the vicinity of Damascus in the northeast section of the watershed. Most of the western half and the northeastern corner of the watershed are very rural with most of the land in forest, pasture, and cultivated cropland. The southeastern section of the watershed is closest to other urban centers within the County, and it is also well connected to the entire Washington metropolitan area via interstate highways. The close proximity and easy access to the urban core makes this the most densely developed portion of the watershed.

Geologically, the southwestern corner of the watershed is comprised of consolidated sedimentary rocks composed of sandstone, red shales, and conglomerates. The remainder of the watershed chiefly consists of metamorphic schists that are highly resistant to erosion.

The soils found in the watershed fall into four associations: (1) Glenelg-Manor-Chester; (2) Manor-Linganore-Glenelg; (3) Conowingo-Aldino-Iredel; and (4) Penn-Lewis-Berry (USDA, 1961). The eastern half of the Seneca watershed lies within the Glenelg-Manor-Chester Association. The combination of the gently sloping terrain and the well drained nature of this association make it the finest agricultural soil in the county. The northwestern third of the watershed is the domain of the Manor-Linganore-Glenelg Association. This association is mostly well drained. However, there are spots that are excessively drained. This type of soil is well suited to general farming although some areas are too steep and/or eroded to be used for row crops. A relatively small area with Conowingo-Aldino-Isredel association soils is located in the west central portion of the watershed to the south of Boyds. These soils have a tough, slowly permeable subsoil of either clay or compacted silty clay. This characteristic makes this association very difficult to manage because of the very slow internal movement of water. Penn-Lewis-berry soils occupy the southwestern corner. Drought-prone and generally low in fertility, these soils tend to be excessively drained.

The drainage system in the Seneca Watershed as shown in Figure 1.2 is composed of several major tributaries, all of which drain to Seneca Creek in the southern most tip of the basin. These streams include Dry Seneca Creek, Little Seneca Creek, and Great Seneca Creek. In addition to these major tributaries, several lesser ones are important to this study. These are Cabin Branch, Whetstone Run, and Long Draught Branch in the southeastern portion of the watershed, Magruder Branch in the northeast, and Ten Mile Run in the north central portion. The long term average discharge of Seneca Creek at the U.S. Geological Survey's Dawsonville gage (which represents almost 80 percent of the entire watershed) is 102 cubic feet per second (cfs). On an annual basis, this translates to 13.7 inches of runoff (overland flow, interflow and baseflow) per year.

Scope of Report

This Final Report is intended to serve as a management tool to assist the local planning community in directly integrating water quality considerations into the planning process. As such, it has been divided into two volumes. This first volume focuses on the major results and conclusions drawn from the analysis. For the sake of clarity, much of the complex technical work supporting the analysis has not been included here. It can be found among the technical papers contained in Volume II. The reader is encouraged to review Volume II to gain a better understanding of the technical basis of this study.

Organization of Volume I

This report has been organized in the following manner:

Chapter 2 presents the major findings of a detailed survey and analysis of past and present water quality conditions in Seneca Creek. Emphasis is placed on obtaining a clearer picture of the physical, chemical and biological nature of the stream. The consequences of past and present water quality conditions on the stream's capacity to sustain aquatic life, human health and recreation are also discussed.

Chapter 3 describes the characteristics and calibration of the Hydrological Simulation Program Fortran (HSPF) model as it was applied to the watershed. The performance of the model is evaluated in several graphical and statistical tests.

In the Chapters 4 and 5, results of a series of model production runs relating to the impacts of future land use plans on the Seneca watershed and the Clarksburg Planning Area are discussed.

Chapter 6 evaluates the relative effectiveness of selected control measures in mitigating the adverse impacts of future development on water quality in the tributary streams and Little Seneca emergency water supply reservoir in the Clarksburg Planning Area. Five stormwater and nonpoint source control strategies are briefly described, and their comparative effectiveness is evaluated in graphical and tabular formats. The control strategies are also screened using a generalized water quality index to provide an overall evaluation of effectiveness of each strategy.

Chapter 7 involves a discussion of the methods used to derive costs for each control strategy. The results of the costing analysis are presented in several different ways. Initial attempts to characterize some of the likely benefits of control strategies are also examined. Finally, the results of the indexing and costing analysis are combined to give planners a general concept of the level of investment required to achieve a given level of water quality.

Finally, in Chapter 8, the major results of the study are integrated, and recommendations for an effective nonpoint source control strategy in the basin are suggested.

Organization of Volume II

Volume II contains various additional technical documentation of various aspects of the study. the contents are as follows:

Technical Paper A. Water Quality in Seneca Creek: A Technical Assessment - This paper details the analysis and interpretations of the available historical water quality data base in Seneca Creek, including an analysis of the NURP monitoring data collected as part of this study.

Technical Paper B. "Application of the Seneca Model to Alternative Land Use Plans in the Clarksburg Planning Area" - presents a brief synopsis of the water quantity/quality projections for each Clarksburg land use plan.

Technical Paper C. "Documentation of the Calibration and Verification of the Seneca Creek Hydrology Model" - a detailed overview of the development of the hydrology component of the Seneca Creek watershed model.

Technical Paper D. "The Seneca Creek Water Quality Model: A Documentation Report" - an extensive presentation of the structure, characteristics and calibration of the water quality component of the overall HSPF model. Also, this paper contains a complete annotated model input stream.

Technical Paper E "Costing Methodologies Employed in the Economic Evaluation of Nonpoint Control Strategies" - a thorough documentation of the methods and assumptions underlying the derivation of stormwater and nonpoint source control cost estimates.

Chapter Two

PAST AND PRESENT WATER QUALITY CONDITIONS IN SENECA CREEK

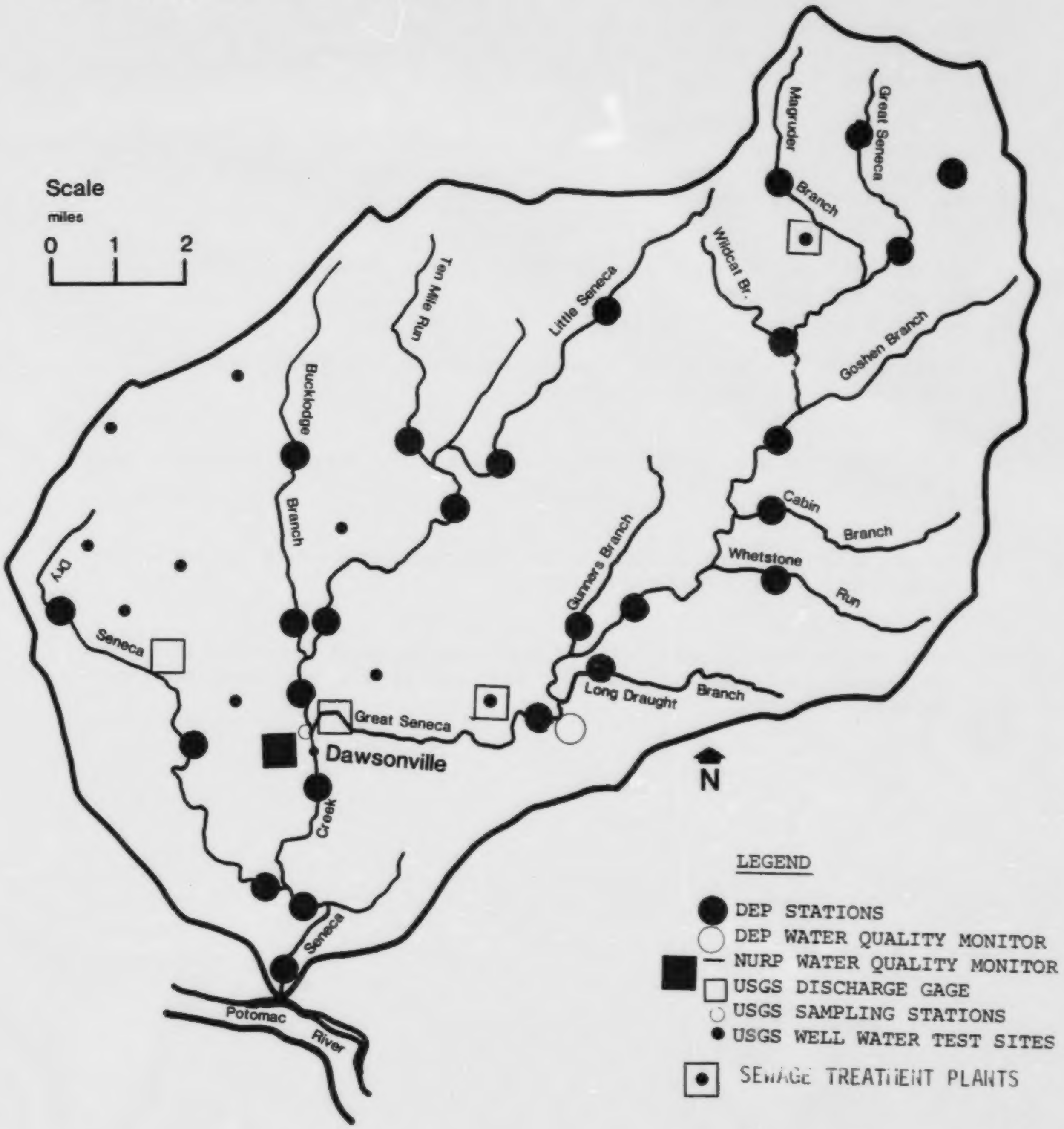
PAST AND PRESENT WATER QUALITY CONDITIONS IN SENECA CREEK

This section presents the major findings of a detailed survey and analysis of the available water quality database in Seneca Creek and its tributaries. The complete analysis is contained in Technical Paper A, Water Quality in Seneca Creek: A Technical Assessment, which can be found in Volume II. The analysis was oriented towards providing a better understanding of the physical, chemical and biological nature of Seneca Creek.

Following a brief discussion of the sources of water quality data which were used to evaluate past and present water quality conditions in Seneca Creek, the following issues will be examined:

- What is the major determinant of water quality in Seneca Creek -- Point or Nonpoint sources?
- What is the present status of water quality in the basin, and how does this compare to historical conditions.
- How does present water quality compare with relevant standards and criteria?
- Have there been any changes in the fish community which can be related to past and present water conditions?
- What is the relative importance of the nonpoint loads generated in Seneca on downstream receiving waters such as Seneca Pool and the Lower Potomac estuary?

Figure 2.1
Sampling Stations in Seneca Creek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Magruder Branch
Great Seneca
Wildcat Br.
Little Seneca
Ten Mile Run
Bucklodge Branch
Goshen Branch
Cabin Branch
Whetstone Run
Gunners Branch
Long Draught Branch
Dry Seneca
Great Seneca
Dawsonville
Creek
Seneca
Potomac River
N
LEGEND
● DEP STATIONS
○ DEP WATER QUALITY MONITOR
■ — NURP WATER QUALITY MONITOR
☐ USGS DISCHARGE GAGE
○ USGS SAMPLING STATIONS
• USGS WELL WATER TEST SITES
⊡ SEWAGE TREATMENT PLANTS

SOURCES OF WATER QUALITY DATA IN SENECA CREEK

Seneca Creek has been the object of substantial water quality monitoring efforts over the past 25 years. Collectively, the water quality data available on Seneca Creek represents one of the most thorough and extensive databases in the entire Washington metropolitan region. Three organizations have conducted the majority of the data collection: the Montgomery County Department of Environmental Protection (DEP), the U.S. Geological Survey (USGS), and the Virginia Polytechnic Institute's Occoquan Watershed Monitoring Laboratory(OWML) under the auspices of the Nationwide Urban Runoff Program (NURP). The location of these sampling stations are depicted in Figure 2.1.

The DEP sampling program is by far the most widespread and extensive single data base. From 1972 through 1980, DEP has maintained a 27 station sampling network on Seneca Creek and its tributaries. Bi-monthly grab samples were collected which provide a snapshot of a variety of nutrients, as well as parameters such as dissolved oxygen, turbidity and acidity. In addition, the DEP has also operated a continuous water quality probe at the juncture of Riffleford Road and Seneca Creek. The probe recorded hourly water temperature, turbidity, dissolved oxygen, conductivity and pH profiles between 1972 and 1980. Finally, special water quality studies in the Upper Little Seneca drainage system have been conducted from 1978-1980 as part of the environmental assessment for the Little Seneca reservoir.

The USGS periodically collected grab samples of nutrients and sediments during the interval 1959 to 1980 at a sampling station adjacent to the disharge gage it operates at Dawsonville, Md.

The final set of water quality time series data was obtained through OWML sampling activities conducted for COG under the Nationwide Urban Runoff Project (NURP). Over fifty biological, chemical and physical water quality constituents were monitored by OWML on a weekly basis, with flow integrated samples taken automatically during storm runoff events. The sampling station was located adjacent to the USGS discharge gage at Dawsonville, Maryland. Monitoring took place between August of 1980 and December 1981. The samples included measurements of various species of nitrogen and phosphorus, total suspended solids, biological and carbonaceous oxygen demand, and toxic substances such as lead, cadmium and chromium. One NURP "priority pollutant" sample was also taken on the mainstem of Little Seneca Creek in early 1982. The priority pollutant sample was taken to detect the presence of some 128 priority pollutants (pesticides, organic chemicals and trace metals) identified by EPA as being of special concern because of their potential toxicity.

RELATIVE IMPORTANCE ON POINT AND NONPOINT SOURCES IN SENECA CREEK

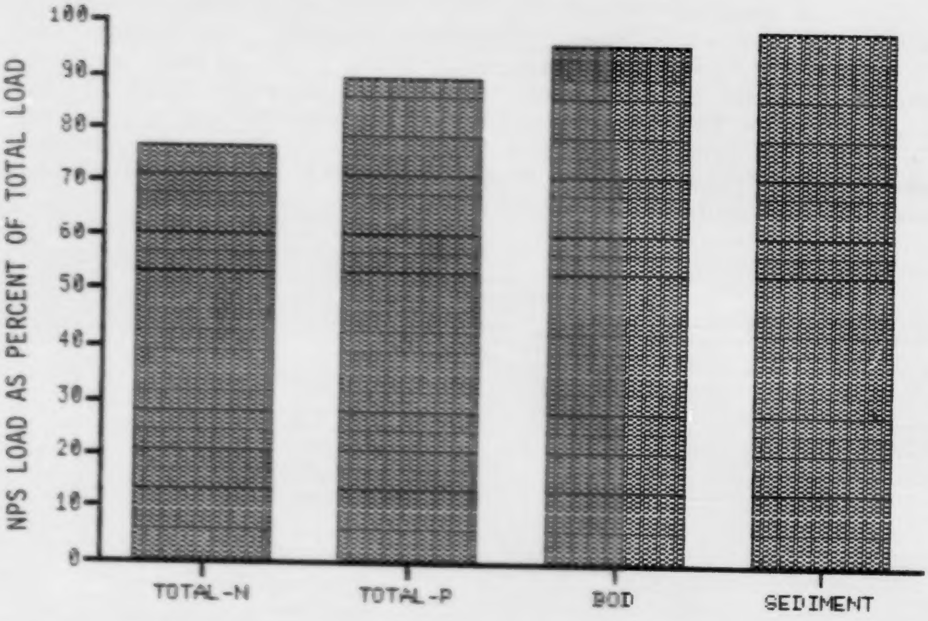
Three major sewage treatment plants (STPs) discharge into Seneca Creek, Great Seneca, Damascus and Poolesville STPs. The location of their discharge outfalls is shown in Figure 2.1. Their collective discharge is approximately 5 million gallons per day (mgd). The Damascus and Great Seneca STPs employ advanced techniques such as nitrification to treat municipal wastes, and as a result their effluent contributes only a minor share of the instream load for any water quality constituent. This is readily apparent in Figure 2.2, in which the STP loads have been factored out of the total water quality loads observed at Dawsonville, during the 1981 water year. For most parameters, the STP contribution is less than 20 percent. One exception is nitrate (one of the end products of the nitrification process), which STPs contribute about 25 percent of the total load.

The Poolesville STP, a small facility (0.3 mgd), was not included in this analysis because it discharges below Dawsonville. This plant does not currently treat wastes at the advanced levels of the other two STPs, but planned upgrades in the next few years will dramatically improve its performance.

By implication, then, nonpoint sources must be considered to be the dominant pathway of pollutants into Seneca Creek. Efforts to improve water quality within Seneca Creek must recognize the fact that nonpoint sources contribute approximately 90 percent of the total load for most parameters.

Figure 2.2

Comparative Importance of Point and Nonpoint Loads in Seneca Creek



MAJOR SOURCES OF NONPOINT LOADS TO SENECA CREEK

Nearly half of the watershed is still devoted to crops and pasturelands that produce the major share of the nonpoint source loads to Seneca Creek. However, as development proceeds in the watershed, stormwater runoff from urban areas is rapidly becoming a significant pollutant loading source. The major sources of nonpoint pollutants within Seneca Creek are outlined below:

Soil erosion in the Seneca Creek watershed is principally generated from croplands and construction sites, while bank erosion and channel scour are chiefly caused by urban stormwater runoff and poor livestock practices.

- Eroded sediments, in turn, are the primary transport vehicle for organic nutrient forms and trace metals such as iron and manganese.

- The chief sources of bacteria to Seneca Creek are livestock pollution, urban stormwater runoff, failed septic systems and natural sources.

- Agricultural areas are the dominant source of nutrients to Seneca Creek at the present time. However, washoff of atmospherically deposited nutrients from urban areas can be expected to become an increasingly significant source as development proceeds in the watershed.

- The two chief sources of trace metals in Seneca Creek are eroded soils and urban stormwater runoff, particularly from areas with a large amount of imperviousness and/or vehicular traffic. High concentrations of trace metals are almost always associated with storm events.

- The tendency towards acidity (pH) observed in the basin appears to be the result of the combined effects of acid rain in storm runoff, subsurface inflow from an acidic aquifer, and instream biological processes. No clear relationship between instream acidity and storm runoff could be developed.

CURRENT STATUS OF WATER QUALITY IN SENECA CREEK

While some water quality indicators remain well within acceptable limits, other indicators suggest that the overall quality of water in Seneca Creek is degraded, particularly in the lower reaches of the stream.

- The well-shaded and aerated waters of Seneca Creek consistently meet State standards established for dissolved oxygen and water temperature in all reaches of the stream. Also, the biological oxygen demand (BOD) exerted on the stream tends to be at moderate to low levels at most times of the year.

- Sediment loading appears to be the most serious water quality problem in Seneca Creek. High rates of erosion coupled with increased channel scouring by stormwater runoff produce persistently high sediment concentrations in Seneca Creek. High sediment loads and increased stormwater runoff volumes and velocities also significantly alter the main stream channel in many reaches, and are an important causal factor in the deterioration of the stream's capacity to sustain a diverse aquatic habitat.

- Bacteria standards are consistently violated throughout the entire Seneca Creek drainage system. Extremely high fecal coliform counts have been routinely measured in tributaries draining both suburban and rural watersheds. In the mainstem of Great Seneca, violations of the state bacterial standard occur in four out of every five measurements.

- Nutrient enrichment (eutrophication) is not usually considered to be a significant problem in free flowing streams such as Seneca Creek. Current nutrient levels, however, appear to be of sufficient magnitude to create eutrophic conditions in existing water impoundments throughout the Seneca basin. In particular, nitrate and total phosphorus concentrations were found to be higher than those reported for other similar streams in the Maryland Piedmont.

- Contamination of the stream by trace metals may be a cause for growing concern. At least seven trace metals violated one or more of the EPA water quality criteria for the protection of aquatic life, human health or human welfare. Several metals -- iron, silver, copper and lead -- violated EPA criteria with a 20 percent or greater frequency. However, it is difficult to assess the actual effect of trace metals on the aquatic community as there appears to be no clear relationship between fish diversity and observed trace metals levels.

- The low buffering capacity of Seneca Creek's soft waters leads to large fluctuations in the pH in the stream. pH levels vary by as much as 6 orders of magnitude, and fall below the 6.5 State Standard from 9 to 48 percent of the time, depending on whether pH is measured in the field or in the lab.

SENECA CREEK WATER QUALITY: PERFORMANCE RELATIVE TO MARYLAND STATE STANDARDS

The State of Maryland has promulgated water quality standards for five instream parameters -- dissolved oxygen, pH, water temperature, turbidity and fecal coliform bacteria. Each standard varies in strictness according to the level of water quality deemed necessary to maintain a specific beneficial use for a particular water body. Four such classes of water quality standards have been established in the state, but only two apply to waters in the Seneca Creek drainage system -- classes I and IV. The class I category is designed to protect aquatic life and use for water contact recreation, while the more recreational class IV standards are structured to protect use for recreational trout waters, in addition to uses covered by class I waters. Little Seneca Creek is the only stream in the watershed which has a class IV designation.

Data on the nature and frequency of standard violations were derived by analyzing at least five years of record from the DEP continuous monitor at Seneca Creek and Riffleford Road. The number of observations upon which calculations were made exceeded a thousand in each case (with the exception of fecal coliform bacteria, which numbered slightly less than one hundred). The results of this analysis are depicted in Figure 2.3.

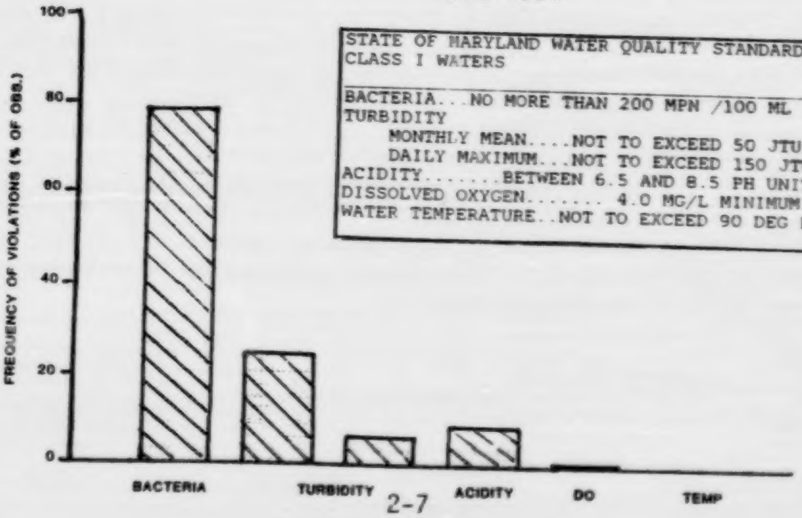
The frequency with which a particular standard was violated varied widely among the four constituents. For example, the fecal coliform bacteria standard was the most consistently violated standard (78 percent of all measurements), while the dissolved oxygen standard was violated with the least frequency (0.0007 percent of all measurements). The difference in violation frequency between the two constituents was nearly six orders of magnitude. The instantaneous pH standard was violated 8.6 percent of the time (48 percent of the time in the 1980-81 lab NURP pH measurements) and the instantaneous turbidity standard was violated 25 percent of the time. Mean monthly turbidity was exceeded at least 6 percent of the time and possibly more often. However, major gaps in the turbidity record at Riffleford Road did not allow for a thorough assessment of monthly turbidity levels. The most severe violations for each constituent were 2.1 mg/l of dissolved oxygen, 240,000 MPN/1000 ml of fecal coliform bacteria, 600 JTUs turbidity and 4.45 pH units of acidity.

Figure 2.3

Water Quality in Lower Great Seneca Creek

Violation Frequency of Maryland Water Quality Standards

1972–1981



SENECA CREEK WATER QUALITY: PERFORMANCE RELATIVE TO U.S. EPA WATER QUALITY CRITERIA

The Environmental Protection Agency has periodically published water quality criteria for use in assessing the impacts of trace metals and pesticides in streams (U.S. EPA, 1976, 1981). Three types of criteria have been generated for protection of aquatic life, human health and human welfare, respectively. In most cases, the criteria level for a given constituent is uniquely determined for each stream, through the use of functional equations relating the hardness of the water to the threshold level of the criteria. The criteria violation analysis is presented in Figure 2.4. The nature and frequency of criteria violations was determined by aggregating all of the DEP, WSSC and NURP trace metal data, regardless of sampling location. More detailed analysis of the trace metal data is in Technical Paper A.

Of the thirteen trace metals considered, only three (Arsenic, Barium and Selenium) consistently were below their respective criteria limit. Two others, (Chromium and Mercury) could not be adequately assessed due to either an insufficient number of samples or because the criteria levels were well below the detection limits. The remaining eight metals have been found, at one time or another, in concentrations in excess of the relative aquatic criteria. There were six violations of aquatic life criteria, three violations of human health criteria and two violations of human welfare criteria.

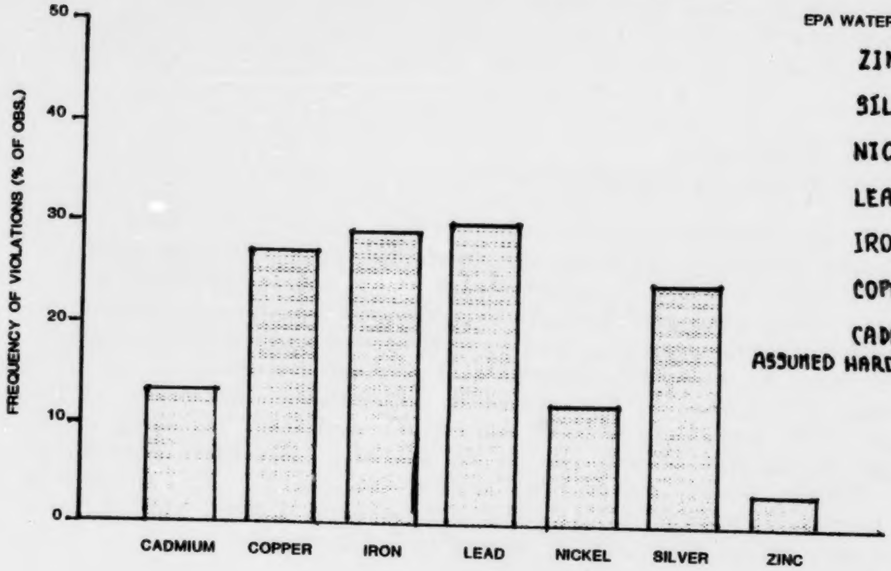
Iron and manganese were the two metals which violated the human welfare criteria. The thresholds of these criteria are set at levels where staining and discoloration begin. In both cases, the frequency with which the criteria was violated was nearly 30 percent. Both constituents are closely allied with the sediments, and it is not surprising that violations of iron and manganese are almost always associated with turbidity violations.

The actual significance of observed violations of the human health criteria (Cadmium, Lead and Nickel), is difficult to assess. First, the cadmium and nickel health criteria apply only when the metals are ingested, either by drinking water or consuming fish. The degree to which either activity occurs in the watershed is not known. Also, the relatively small number of observations for these metals makes it difficult to assess whether or not the violations are chronic in nature, or only occur during storms.

On the other hand, aquatic life is usually much more sensitive to high trace metal concentrations. As a result, many more violations are registered for aquatic life criteria than any other. The violation data in Figure 2.4 clearly suggest trace metals may be having a pervasive impact on aquatic life, in terms of extremes and frequency of violations. For example, the maximum reported silver, copper and cadmium are 42, 11, and 45 times higher than the respective criteria. Likewise, the frequency with which certain trace metals violated the criteria approached near chronic levels. For example, cadmium exceeded the instantaneous criteria over 13 percent of the time, copper 12 to 27 percent, iron 17 percent, lead 20 to 40 percent, silver 24 percent, and zinc 3 percent of the time. Given the high frequencies above the criteria threshold of some of the metals, more concentrated heavy metals sampling, possibly including fish tissue analysis or bioassay appears to be a warranted avenue for future research.

Figure 2.4

Violation Frequency of EPA Water Quality Criteria in Seneca Creek
Instantaneous Aquatic Life Criteria

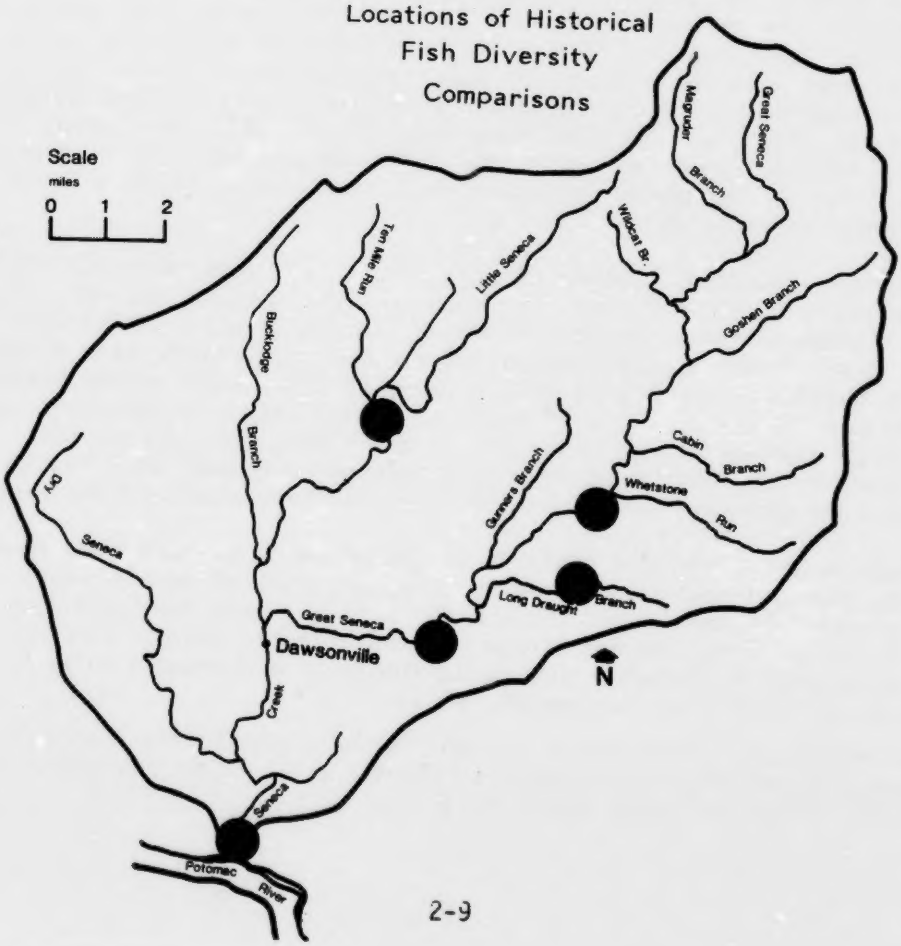


EPA WATER QUALITY CRITERIA THRESHOLD

ZINC	117.5 ppb
SILVER	0.51 ppb
NICKEL*	38. ppb
LEAD	39.2 ppb
IRON	1000. ppb
COPPER	7.1 ppb
CADMIUM	0.84 ppb

ASSUMED HARDNESS = 29.8 ppm

Figure 2.5
Locations of Historical
Fish Diversity
Comparisons



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Creek
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Seneca
Potomac River

HISTORICAL AND SPATIAL TRENDS IN FISH DIVERSITY AND ABUNDANCE IN SENECA CREEK

Many investigators have conducted fish surveys in Seneca Creek and its tributaries over the last six decades (Allison, 1971; Dietemann, 1974; Goudegeon, 1981; Howden and Mansuetti, 1949; Hughes, 1973; Radcliffe and Walsh, 1916; Whittaker and Brush, 1977). Table 2.1 presents a comparative summary of those studies which had similar sampling locations (see Figure 2.5 for locations).

Changes in Species Diversity in Great Seneca Creek and Long Draught Branch

Several definitive trends clearly emerge from Table 2.1. First, it is evident that species diversity has been substantially reduced at the mouth of Great Seneca and also in Long Draught Branch. Possible explanations in each case differ. Long Draught Branch experienced rapid urbanization in the 1960s and 1970s and the resulting sediment load and hydrological changes appear to have lead to the deterioration of stream habitat. It is more difficult to assess the causes of the dramatic reduction in diversity at the mouth of Seneca. The waters of the Potomac River and the prevailing winds produce a large backwater effect, which causes the lowermost portion of Seneca Creek (below River Road) to become stagnant. As a result, sediments and nutrients do not get flushed out, except during storms, and this phenomenon may affect the viability of the fish community.

Changes in Diversity in Little Seneca Creek

The number of species present does not appear to have changed appreciably in the predominantly agricultural Little Seneca Drainage system. This system (including Ten-Mile Creek and Cabin Branch) has historically been the most diverse system in the entire drainage basin. A total of thirty-two species were collected at all the Little Seneca stations during the 1976 and 1971 Fish surveys (Whittaker and Brush, 1977; Goudgeon, 1982). The Little Seneca watershed also contains the largest and most diverse game fish population in the basin, including small mouth bass, rainbow trout, and an assortment of pan fish.

Although the total number of species has remained relatively constant over the years in Little Seneca, the composition of species has not. Species such as Cutlips minnow, swallowtail shiner, comely shiner, fallfish and white crappie have either disappeared or have become extremely rare since the Radcliffe and Walsh survey of 1916. Other species, such as the tesselated and greenside darters, the riverchub and the bluegill, pumkinseed, green and hybrid sunfish, have increased in dominance over the period. (The appearance of sunfish since the 1916 survey suggests that the present population are derived from sunfish that escaped from stocked farm ponds.)

Rainbow trout are also found in the basin now, although their presence is due to the put and take trout stocking program of recent years. The single greatest "winner" over the last 60 years has been the blacknose dace, which is now the most common forage fish found in the basin. The blacknose dace's dominance is probably due to its ability to withstand a large range of environmental conditions (Dietemann, 1974).

An additional trend that is evident in the Little Seneca comparisons is that more species which are collected recently are rare or extremely rare in abundance, compared to the 1916 survey.

Table 2.1

Historical Fish Diversity Comparisons in Seneca Creek

FISH SPECIES	LITTLE SENECA CR.				LONG DRAUGHT BR.		GREAT SENECA, MOUTH		GREAT SENECA DAWSONVILLE		LOWER GREAT SENECA	
	1914	1973	1974	1976	1971	1974	1949	1974	1949	1974	1949	1974
Blacknose Dace *R. atratuls*	■	■	■	■	■	■				■		■
Longnose Dace *R. cataractae*	■	■	■	■								■
Rosyside Dace *C. funduloides*	■	■	■	■								
Rosyface Dace *N. rubellus*										■	■	■
Bluntnose Minnow *P. notatus*	■		■	■			■		■			■
Cutlips Minnow *E. maxillingua*	■			□								
Silverjaw Minnow *E. buccata*		■	□						■		■	
Swalotail Shiner *N. procne*							□					
Spotfin Shiner *N. spilopterus*	■	■	■	□	■		■			■	■	■
Comely Shiner *N. amoenus*	■								■			
Common Shiner *N. cornutus*	■			■	□		□					■
River Chub *N. micropogon*	■			□						□		■
Creek Chub *S. atromaculatus*	■	■	■	■	■	□	■				■	■
Fallfish *S. corporalis*	■						■				■	
Stoneroller *C. anomalum*												
Goldfish *C. auratus*							■					
White Sucker *C. commersoni*	■	■	■	■	■				■		■	
Hog Sucker *H. nigricans*	■	■		■								
Eel *A. rostrata*	■	■		■				□		■		
Madtom Catfish *N. insignis*	■	□										
Channel Catfish *I. punctatus*							■	■				
Fantail Darter *E. flabellare*	■		□	■						□		■
Tesselated Darter *E. olmstedi*	■	■					□				■	□
Greenside Darter *E. blennioides*		□		□								■
Mottled Sculpin *C. bairdi*	■	■	□	■	■						■	□
Rockbass *A. rupestris*		■								□		
Smallmouth Bass *M. dolomieu*	■		■	■			■				■	
White Crappie *P. annularis*							■					
Bluegill Sunfish *L. macrochirus*		□		■				■				
Redbreast Sunfish *L. auritus*	■	□										
Pumpkinseed Sunfish			■	■				□				
Green Sunfish *L. cyanellus*												□
Total No. of Species	20	16	12	18	5	2	11	4	4	7	9	14
% of Species collected that were rare.	0	4	3	4	1	1	2	2	0	4	0	3

NOTE: Salmonoids (e.g., Brown and Rainbow trout) were not included on the species list since they do not appear to naturally reproduce. Most of the specimens were collected in the 1970's in Little Seneca Creek, and are relicts of the annual put and take trout stocking program

SOURCES: Radcliffe and Welsh (1916), Howden and Mansveti (1949), Allison (1971) Hughes (1973) Dieteman (1974) Whittaker and Brush (1976).

LEGEND
■ abundant
□ rare or extremely rare

Species Richness

Species "richness" (as represented by number of species present) has increased in the two mainstem Great Seneca stations, from 4 to 7 at Dawsonville and 9 to 14 at Rte. 270 and Seneca Creek. It is immediately apparent in both comparisons that a pronounced shift in species composition has occurred. For example, at the survey station at Dawsonville, no species collected in 1949 was found in 1974. Whether or not the new species are hardier than the ones that were replaced is a very difficult question to answer. Again, it is interesting to note that the highly tolerant blacknose dace was found at both the Dawsonville and Rte. 270 stations in 1974 but was not collected in the 1949 survey. Also, sportfish were not found at either locale during the 1974 survey (as well as Whittaker and Brush 1976 survey of Upper Great Seneca).

Another very interesting trend is that species diversity declines in Great Seneca as one travels downstream. This trend is most evident in the data of Dietemann (1974). For purposes of this analysis, Dietemann's fourteen survey stations along the Seneca mainstem were aggregated within three larger segments shown in Figure 2.5 -- Segment 1; Upper Great Seneca (headwaters to MD 355) Segment 2; Lower Great Seneca, (Clopper Road to Riffleford Road) and Segment 3; Lower Seneca (Dawsonville to confluence with Potomac). The mean number of species collected per station within each segment declined from 11.9 in Segment 1 to 7.6 in Segment 3. Likewise, the total number of species recorded in each segment followed a similar progression, with 21 being reported in Segment 1, 18 in Segment 2 and 16 in Segment 3. These trends seems to contradict the expected patterns of species diversity commonly observed in undisturbed streams. Undisturbed streams are usually thought to exhibit more diversity as the stream becomes wider, deeper and less thermally variable (VanHouten 1981, Cummings, 1973). Thus, the declining diversity seems to imply that there is some constraint on fish populations in the lower reaches of Great Seneca Creek.

Relationship Between Water Quality and Stream Habitat

The previous section has documented the wide variability in fish diversity, abundance and composition observed throughout the Seneca Creek drainage system. The question that arises is whether the variability is due to differences in ambient water quality or differences in aquatic habitat, or some combination of both factors.

The relationship between overall water quality and observed levels of fish diversity is not entirely clear. For example, the water quality ratings issued by the DEP for the most and least diverse portions of Seneca Creek have been similar throughout most of the 1970s. The DEP water quality rating, a weighted index of annual averages of nine physical, chemical and microbiological parameters, also remained in the permissable range at both locations. This is not to imply that individual water quality constituents are not important factors influencing fish diversity at certain times and locations. For example, toxic shocks of trace metals (such as silver and copper), and extended periods of turbidity, probably do have a significant impact on fish populations in Seneca Creek (Dietemann, 1975). However, even these constituents are not systematicaly related to observed patterns of fish diversity. The highest reported copper and silver concentrations, and the second highest lead observations, have been measured in the diverse Ten-Mile Creek and Little Seneca draiange system.

Of all the water quality constituents examined, turbidity is probably most closely related to fish diversity patterns. Turbidity is greatest in the lower reaches where, in general, the lowest number of species have been recorded. Whether this reflects the actual water column impacts of turbidity or the associated habitat deterioration is not known at present.

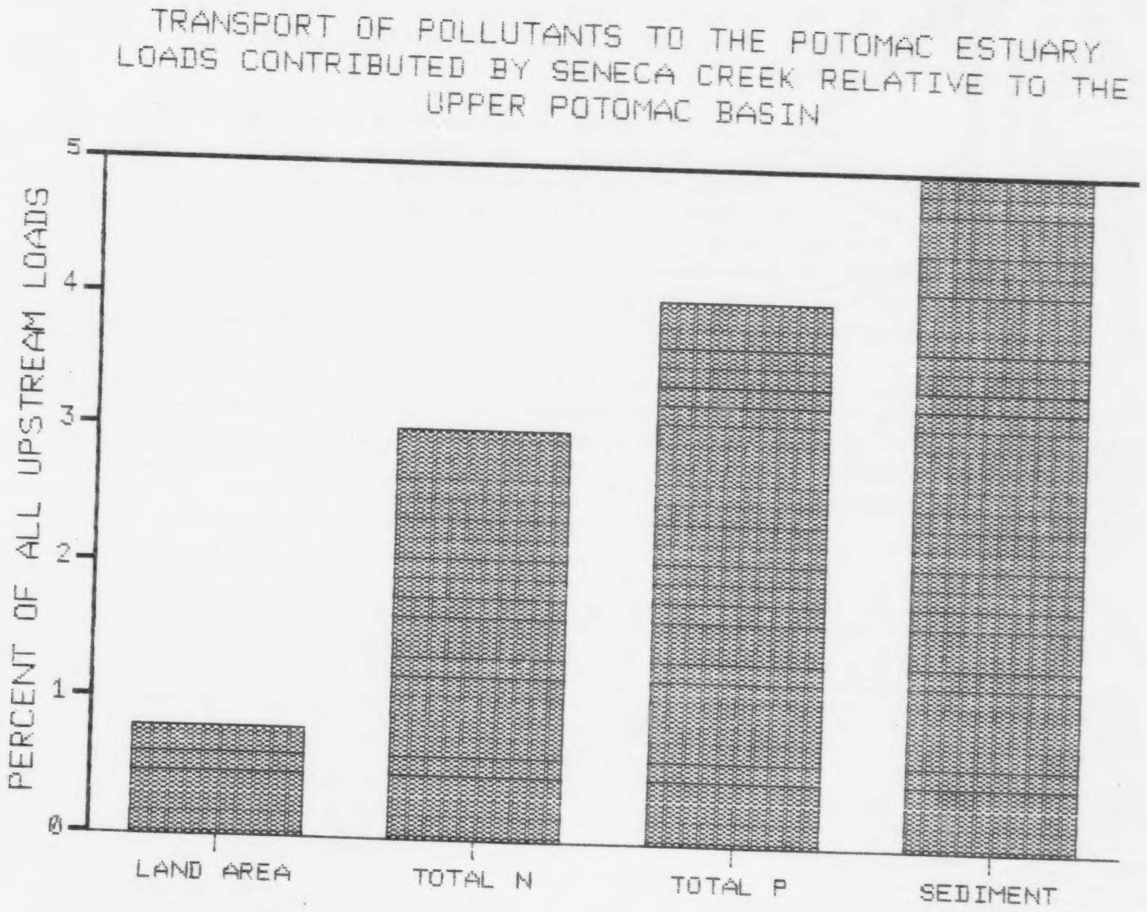
Factors Affecting Stream Habitat

Habitat deterioration in streams is usually characterized by: 1) shifting, unstable and coarsely textured streambeds; 2) reductions in the populations of benthic insects and aquatic vegetation upon which fish depend; 3) wider and shallower stream channels that have exposed fish to greater thermal variability and have less pools and riffles; and, 4) extreme variations in stream flow (i.e., an increased frequency of both floods and extended baseflow periods).

Several investigators have noted that urbanization, specifically an increase of watershed imperviousness, has induced such conditions in streams of the Maryland Piedmont and elsewhere (Fox, 1973; Hammer, 1972; Klein, 1980; Yorke and Herb, 1978). Changes in the nature of the streambed and channel have also been attributed to deposition of coarse sediments in streams experiencing high sediment load, usually from erosion of construction sites in rapidly urbanizing areas. Also, bank erosion caused by higher stormwater flows from urbanized areas can produce similar effects.

While Seneca Creek as a whole is not extensively urbanized at present (less than 5 percent of the basin is impervious), several sub-watersheds in the rapidly growing areas of Damascus, Gaithersburg and Clarksburg are from 25 to 70 percent impervious. Klein suggests that severe degradation of stream habitat occurs when watershed imperviousness exceeds 30 percent (1980).

Figure 2.6


TRANSPORT OF POLLUTANTS TO THE POTOMAC ESTUARY
LOADS CONTRIBUTED BY SENECA CREEK RELATIVE TO THE UPPER POTOMAC BASIN
PERCENT OF ALL UPSTREAM LOADS
5
4
3
2
1
0
LAND AREA
TOTAL N
TOTAL P
SEDIMENT

TRANSPORT OF POLLUTANTS TO THE POTOMAC ESTUARY

The pollutant load from Seneca Creek is quickly delivered to the headwaters of the Potomac estuary. Tracer dye experiments conducted by Brennan and Lee (1978) suggest that the travel time from the upper reaches of Seneca Creek to Chain Bridge (the head of the Potomac estuary) is on the order of one to two days. Given this quick travel time, it can safely assumed that the majority of the Seneca pollutant load remains in suspension all the way to the estuary. As the Potomac estuary has experienced eutrophication problems in the past, it is of importance to determine the magnitude of the Seneca Creek loads, relative to all other upstream loads.

To address this issue, annual total nitrogen (TN), total phosphorus (TP), and total suspended sediments (TSS) loads for the 1980-81 water year in Seneca were computed using a modification of the stratified ratio technique advocated by Dolan et. al. (1981). Briefly, flow weighted means were calculated for storm and baseflow periods from the 1980-1981 NURP data collected by OWML. These, in turn, were multiplied by the total number of days of baseflow or stormflow during the water year to obtain the annual load. Since the 1980-81 water year was relatively dry in comparison to other years of record, the estimate pertains only to dry years. Thus, the dry-year loads for TN, TP, and TSS were 492,650 lbs, 35,418 lbs, 12,310 tons, respectively. When these loads are compared to the total dry year loads (above the fall line) computed by Hartigan (1982) of 16,600,000 lbs TN and 854,000 lbs TP, Seneca Creek appears to contribute 2.97 percent of the dry year fall line TN load and 4.15 percent of the dry year TP load. While these percentages are relatively small, it should be kept in mind that the Seneca Creek watershed occupies only 0.8 percent of the total land area of the Potomac basin above the fall line, so that Seneca Creek can be said to deliver about 4 times as much TN and 5 times as much TP per acre to the Potomac estuary, as the rest of the upper 11,000 square miles of the Potomac basin (Figure 2.6). This high unit area loading rate not only reflects the larger loadings of the Seneca Creek watershed, but also the watershed's close proximity to the estuary.

Insofar as sediment is concerned, it has been estimated that under high discharge conditions, Seneca Creek supplies about 5 percent of the Potomac River sediment load (Dow Chemical), 1972). This high unit area loading is chiefly due to two factors. First, Seneca Creek generates a higher sediment load than any other Maryland tributary to the Potomac (with the exception of the Monocacy River; MSSCC, 1976). Secondly, since there is such a short travel time for sediment from Seneca compared to more distant tributaries, the sediment is less likely to be deposited before it reaches Chain Bridge.

The clear implication of the foregoing discussion is that, pound for pound, nutrient and sediment control may be more efficient if applied to Seneca Creek rather than distant tributaries. Thus, if protection of the aquatic resources of the Potomac estuary is a primary management concern, then control of nonpoint loadings from local streams such as Seneca Creek would be a logical first step.

SUMMARY: CONSEQUENCES OF PRESENT WATER QUALITY

Current water quality and stream habitat conditions impaired several beneficial uses of Seneca Creek -- aquatic life, aesthetics, fishing, and other allied forms of recreation.

- As in many streams throughout the region, consistently high bacterial levels in the entire Seneca Creek drainage system appear to preclude the use of the stream for water contact recreation under present Maryland water quality standards.

- Stream waters in the lower reaches of Seneca Creek are turbid three out of every four days, on average. From an aesthetic standpoint, the discolored water and unsightly debris significantly detract form the recreational experience.

- Deterioration of water quality is often manifested in changes in the structure of the fish community. An analysis of historical fish survey records indicates that the abundance, diversity, and composition of the fish community has changed over the last sixty years. Major elements of the change are: 1) the disappearance of game fish from the mainstem of Great Seneca; 2) an increase in the number of species with a rare or extremely rare abundance; 3) profound changes in the composition of fish species typified by the replacement of environmentally sensitive species by hardier ones; 4) substantial loss of fish diversity at the Mouth of Seneca and in Long Draught Branch; 5) constant or slightly declining diversity in Little Seneca, and 6) an increase in diversity in the mainstem of Great Seneca.

- Historical changes in the structure of the fish community appear to be as much a response to habitat deterioration than changes in overall water quality. Deterioration of habitat can be attributed to deposited sediments and the effect of imperviousness in creating unstable flow regimes.

- Nutrients and sediment generated within the Seneca watershed are eventually delivered to the Lower Potomac River, an estuarine system where eutrophication has been a persistent concern. While Seneca Creek contributes only a fraction of the total annual pollutant load to the Potomac River at the Fall line, it is estimated that four times as much total nitrogen, five times as much total phosphorus, and six times as much sediment are transported on a per acre basis, when compared to the average per acre loadings from the combined upper Potomac basins.

Chapter Three

DEVELOPMENT OF THE SENECA CREEK WATERSHED MODEL

DEVELOPMENT OF THE SENECA CREEK WATERSHED MODEL

An integral part of the Seneca study was the development of prototype watershed simulation model. The HSPF model (Hydrocomp, 1980) was selected for this purpose since it represented the most comprehensive hydrology and water quality model available when the study was initiated. HSPF, which stands for Hydrological Simulation Model-Fortran, is a continuous watershed and receiving water model which incorporates major elements of EPA's Nonpoint Source model (Donigian and Crawford, 1976) and Agricultural Runoff model (Donigian and Davis, 1978). In brief, the model accomplishes soil moisture accounting, runoff production, sediment and nonpoint source pollution generation, and the routing of water and pollutant loads through a channel system.

This chapter will highlight the following features of the development of the Seneca Creek model:

- The structure and capabilities of the HSPF model;
- Major characteristics of the application of the model to the Seneca Creek model;
- The calibration process; and,
- Presentation of simulation results.

A complete discussion of all aspects of the Seneca Creek Watershed Model can be found in the two technical modeling papers in Vol. II of this report. Technical Paper C describes the development and calibration/verification of the hydrology component of the overall model, while Technical Paper D documents the water quality aspects of the model. Each paper contains an extensive discussion of model structure, input preparation, parameter selection, calibration and verification methods, results and model evaluations. Also, each technical paper contains a complete listing of the model input stream.

Figure 3.1
Basic Operation of the HSPF Model

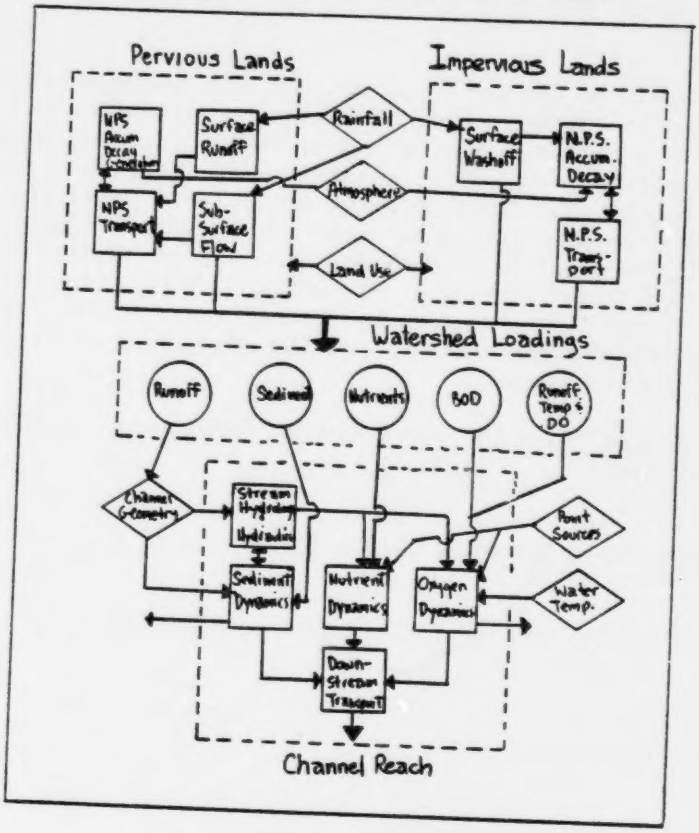

Pervious Lands
Impervious Lands
NPS Accum Decay
Surface Runoff
Rainfall
Surface Washoff
N.P.S. Accum. Decay
NPS Transport
Sub-Surface Flow
Atmosphere
N.P.S. Trans-port
Land Use
Watershed Loadings
Runoff
Sediment
Nutrients
BOD
Runoff Temp & DO
Channel Geometry
Stream Hydrology & Hydraulics
Point Sources
Sediment Dynamics
Nutrient Dynamics
Oxygen Dynamics
Water Temp.
Down-Stream Transport
Channel Reach

Table 3.1
Key Processes Simulated by HSPF

PERVIOUS LANDS

- Surface and subsurface runoff
- Soil erosion
- Generation/transport of NPS pollutants

IMPERVIOUS LANDS

- Surface runoff and solids washoff
- Accumulation/washoff of NPS pollutants

CHANNEL REACHES

- Stream hydrology/hydraulics
- Transport of water quality constituents
- Point source loadings
- Streambank erosion/sediment deposition
- Dissolved oxygen budget and nutrient transformations

STRUCTURE OF THE HSPF MODEL

A simplied representation of the basic operation of the HSPF model is supplied in Figure 3.1. Land uses within the watershed are divided into two distinct categories -- pervious and impervious land surfaces. Runoff and nonpoint loads generated from pervious and impervious lands within each subwatershed are delivered to the appropriate stream channel reach. Each channel reach possesses its own distinctive hydraulic and geometric properties. The channel reaches are connected to each other so as to portray the general features of the drainage network of the watershed. Water quality loads are sequentially transported along the reach network, after adjustments have been made to account for changes in loads due to physical and biological processes. Concentration of water quality constituents are determined by averaging the load over the entire runoff volume contained in the reach during the hourly simulation interval.

The specific physical, chemical and biological processes which were simulated in the context of the Seneca Creek Watershed Model are presented in Table 3.1 A general description of how each key process is simulated by HSPF follows. For additional comments, see the annotated input stream in Technical Paper D.

Pervious Lands: Surface and Subsurface Runoff

The flux of water in a pervious area represents a rough balance between the supply of water via precipitation, and losses of water through evapotranspiration, surface/subsurface outflows, and subsurface storage. The HSPF model relies on conventional soil moisture accounting techniques to represent the flux of water between various storage components. These include interception storage, surface detention, upper and lower soil water storages and the active groundwater pool. The relative size of each of these storage components is a function of the physical characteristics of the specific land use and soil type. Outflows from storage component are governed by moisture availability, the rates of transmission between storages, and their relative water holding capacity.

Outflows to streams are allocated in the following manner. Incoming precipitation falls on the land surface where it may infiltrate into the upper soil layer at a rate determined by the texture of the soil. If the rainfall intensity is greater than the infiltration capacity, the excess water is routed as surface runoff, subject to surface detention, and regulated by the characteristics of the overland flow plane. The water which infiltrates into the upper soil layer may travel laterally and emerge as interflow, or can percolate to the lower soil zone or groundwater pool, where it will eventually become baseflow.

Pervious Lands: Generation of Sediment

The generation of sediment from pervious surfaces is essentially depicted as a two stage process. In the first stage, sediment particles are detached from the soil matrix during storm events at a rate determined by the intensity of incoming rainfall, the extent of vegetative cover, and the erodibility of the soil. These particles, form the detached sediment pool. (A second and somewhat less significant contribution to this pool is made by atmospherically deposited sediments, i.e., dust and dryfall.) The second stage simulates the washoff and transport of detached sediment in overland flow, based on the transport capacity of surface runoff. This is largely a function of the length, slope and roughness of the overland flow plane.

Pervious Lands: Generation and Transport of Nonpoint Constituents

There are several possible routes that a given nonpoint constituent (X) can take to travel from the watershed to the watercourse. If X is closely associated with soil particles, it can be transported out in fixed proportion to the quantity of eroded sediments. If X is more soluble, it can leave the watershed via either baseflow or interflow, in a fixed proportion to the outflow volume. Finally, if X tends to accumulate directly on the land surface (e.g., through atmospheric deposition) it can be conveyed to the stream directly in surface runoff. In reality, most nonpoint source constituents follow more than one route to reach the stream.

The amount of a constituent which is available for transport at any given time is set through the use of either potency factors (for sediment associated constituents) or accumulation rates (for surface washoff).

Impervious Lands: Surface Runoff

Since there is no means for incoming rainfall to precolate through the soil in an impervious area, most of the rainfall is directly routed to the stream channel, subject of course, to detention storage and evaporation. The rate at which the runoff is delivered to the stream is also regulated by the characteristics of the overland flow plane.

Impervious Lands: Solids Washoff

Sediments accumulate on impervious areas at a specified rate between storm events. This accumulation accounts for dryfall and contributions of dust and other organic materials deposited by the wind and other atmospheric processes. During storms, these sediments can be washed off in overland flow. The quantity of sediment washoff delivered to streams is governed by the size of the accumulated sediment pool and the quantity of surface runoff generated over the simulation interval.

Impervious Lands: Washoff of Nonpoint Constituents

In this modeling application, it was assumed that the only means for a constituent to reach the stream channel was through the direct washoff of the accumulated constituent in overland flow. As with sediment, the quantity of a constituent in washoff is determined by the rate of constituent accumulation between storms (generated chiefly through atmospheric deposition and other urban activities), and the quantity of surface runoff generated over the simulation interval.

Channel Reach: Hydrology/Hydraulics

Flows from upstream channel segments and localized drainage are routed through each reach at a rate based on the reaches' distinct hydrological and hydraulic properties. These are chiefly derived from channel geometry and estimates of channel roughness. The model calculates the stage, discharge, volume and flow-thru time for each simulation interval. A second set of hydraulic variables (which are subsequently used in other channel reach subroutines) are derived from the flow/geometry relationships. These include average velocity, bed shear velocity and shear stress, and hydraulic radii.

Channel Reach: Transport of Nonpoint Constituents

The constituent loads delivered from pervious and impervious lands are entrained in plug flow, and are longitudinally advected from reach to reach, based on the prevailing flow characteristics. Those constituents which do not materially change over time are treated as conservative substances, while those are subject to transformations are treated independently.

Channel Reach: Point Source Loadings

Mass loads contributed from point sources (in this application, only municipal sewage treatment plants) are added to the specific reach on an hourly basis.

Channel Reach: Sediment Dynamics

The incoming load is separated into three different size fractions within the reach -- sand, silt, and clay. Each fraction of the sediment load is then simulated independently of the others. Individual fractions of the suspended sediment loads are conveyed through the reach system and maintained in suspension, subject to adjustment for deposition due to settling (-), or channel scour and streambank erosion (+).

The sediment dynamics algorithms in HSPF simulate the exchange of sediment channel storage and suspended storage, and vice versa. If the hydrodynamic conditions in the reach are not sufficient to carry the entire suspended sediment load, suspended sediment gradully enters into channel storage, at a rate governed by the settling rates of each size fraction. If, on the other hand, hydrodynamic conditions within the reach are more than sufficient to carry the suspended load, (e.g., water velocites are high) than sediment contained in channel storage (i.e., the streambed) may be released to the suspended sediment load. This flux is triggered when the bed shear stress is raised above a critical threshold level. The rate of exchange is based on a first order scour equation.

Channel Reach: Dissolved Oxygen Budget

The dissolved oxygen (DO) budget is calculated from the dynamic interaction of many factors. Initial DO levels are based on the oxygen content of incoming surface and subsurface waters, and upstream runoff. Adjustments in DO levels are made in response to changes in ambient stream water temperature, reaeration, benthic and biochemical oxygen demands, surface gas invasion, and advection.

Channel Reach: Nutrient Transformations

Changes in the concentration of ammonia-nitrogen and nitrate nitrogen due to nitrification processes, ammonia vaporization, and ammonification of oxidized BOD materials are monitored in this subroutine. Rates are based on first order temperature kinetics.

APPLICATION OF HSPF TO SENECA CREEK

Input Data Requirements

The application of a continuous simulation model on a watershed-wide scale requires the preparation of a large variety of input data. Some of the more important inputs include:

- Meteorological inputs. Hourly rainfall and daily evapotranspiration values must be supplied to drive the soil moisture and water balance calculations.

- Soils data. Aggregated soil data are needed to determine soil moisture storage and erosion potentials.

- Channel cross-section data. Channel geometry is required to define the hydrological and hydraulic properties of each channel reach.

- Land Use Distributions. These distributions are used to define the unique hydrological and nonpoint characteristics of different parts of the watershed.

- Point Source Loadings. The flow and loads from basin STPs must be input on a hourly basis to accurately simulate stream conditions, particularly during baseflow periods.

- Water Temperature. An hourly time series of water temperature must be supplied to govern the rates at which instream processes occur.

- Observed runoff and pollutant loads must be derived so that they can be directly compared with simulated values.

The methods and sources used to derive these inputs are discussed in considerable length in the relevant Technical Papers.

Land Use Categories Employed

Six land use categories were included in the model application (Table 3.2). These categories were selected so as to emphasize the differences in imperviousness, hydrological response, vegetal cover, soil erodibility and nonpoint loadings among land uses. The acreage in each land use category was determined from the detailed 1980 survey of land use in the Seneca basin (M-NCPPC, 1982).

Representation of the Seneca Basin

The Seneca Creek drainage basin was represented with 12 interconnected channel reaches. The relation of reaches to each other in this drainage system is pictured in schematic form in Figure 3.2. Eleven major subwatersheds are drained by the channel system. These subwatersheds generally follow the major drainage divides within the basin, and have been aggregated from a group of 118 subwatersheds above Dawsonville that were utilized in a stormwater management study (CH2MHILL, 1975). The location of the subwatersheds is depicted in Figure 3.3.

Table 3.2
Land Use Categories Employed in the Model

- Forest/idle
- Croplands
- Pasture
- Low density development
- High density development
- Impervious areas

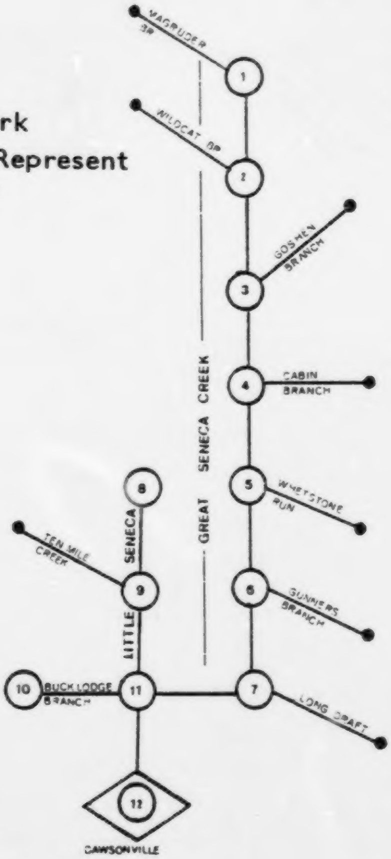
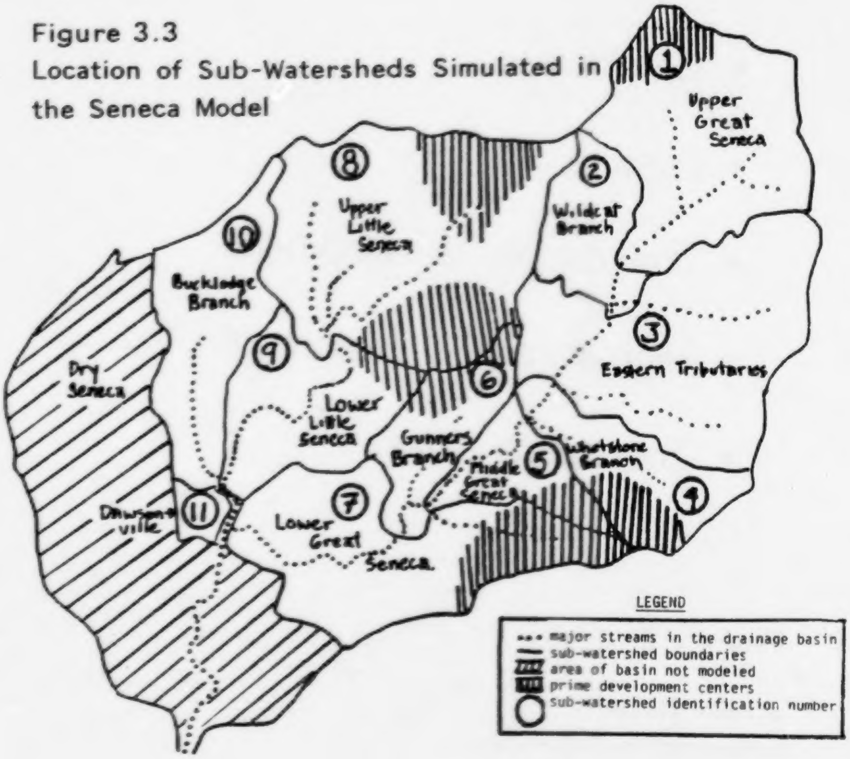

MAGRUDER BR
1
WILDCAT BR
2
GOSHEN BRANCH
3
CABIN BRANCH
4
WHETSTONE RUN
5
GUNNERS BRANCH
6
LONG DRAFT
7
GREAT SENECA CREEK
8
LITTLE SENECA
TEN MILE CREEK
9
10
BUCK LODGE BRANCH
11
12
DAWSONVILLE

Figure 3.2

Stream Network
Employed to Represent
Seneca Creek

Figure 3.3
Location of Sub-Watersheds Simulated in the Seneca Model


1
Upper Great Seneca
2
Wildcat Branch
3
Eastern Tributaries
4
Whetstone Branch
5
Middle Great Seneca
6
Gunners Branch
7
Lower Great Seneca
8
Upper Little Seneca
9
Lower Little Seneca
10
Bucklodge Branch
11
Dawsonville
Dry Seneca
LEGEND
major streams in the drainage basin
sub-watershed boundaries
area of basin not modeled
prime development centers
sub-watershed identification number

SUBWATERSHED	SIZE (Acres)	% AGRICULTURAL 1980	% IMPERVIOUS 1980
1. Upper Great Seneca	8,850	42.0	3.9
2. Wildcat Branch	2,966	53.9	2.0
3. Eastern Tributaries	10,658	44.0	6.1
4. Whetstone Run	3,265	37.2	15.9
5. Middle Great Seneca	2,124	19.7	17.2
6. Gunners Branch	5,002	41.8	10.6
7. Lower Great Seneca	8,503	46.5	7.6
8. Upper Little Seneca	13,590	43.8	5.9
9. Lower Little Seneca	4,615	47.6	3.7
10. Bucklodge Branch	5,297	60.7	1.1
11. Dawsonville	1,153	65.0	1.1
ENTIRE WATERSHED	64,324	45	6.2

THE CALIBRATION PROCESS

Model calibration is an iterative procedure of parameter evaluation and refinement where simulated water quality outputs are compared to observed data. In the Seneca application, calibration followed a two stage process; the hydrology component was calibrated first, and once a reasonable agreement between observed and simulated runoff had been achieved, the water quality component was calibrated. The specific steps and calibration tests for each stage are outlined below. The process generally followed the procedures set forth in the HSPF application guide (Anderson Nichols, 1982).

Hydrology Calibration

1. Watershed data, obtained from published reports and communication with M-NCPPC and other local agencies, were compiled and evaluated.
2. Initial parameter sets were constructed, based on watershed characteristics identified in Step 1.
3. The streamflow measurements at the USGS gage were partitioned into two periods: 1967 to 1970 and 1971 through 1975. The first interval was employed as the calibration period; the latter interval was used for verification purposes. The 4-year duration of the calibration interval was selected to encompass a wide range of rainfall and streamflow conditions.
4. The model was run for the calibration interval using the parameter set constructed in Step 2. Observed and simulated streamflow were compared with this comparison serving as the base case.
5. The initial parameter set was incrementally adjusted (calibrated) in an iterative manner to minimize the difference between the observed nad simulated discharge.
6. Calibration of the model proceeded along the following hierarchial sequence of increasing temporal resolution: annual water yields, monthly water yields, daily flows, and individual storm hydrographs.
7. Flow duration analysis was performed on both observed and simulated data sets. This comparison assessed the model's capability to simulate the entire distribution of flow events that can be expected in the watershed.
8. The HSPF model was considered to be "calibrated" once it had achieved a reasonably good correspondence with the observed data for all levels of calibration indicated in Steps 6 and 7.
9. The final parameter set of the "calibrated" model was then run, unchanged, over the 5-year verification period. The observed and simulated data sets from the verification interval were then subjected to the same evaluation criteria set forth in Steps 6 and 7.

Water Quality Calibration

1. A calibration interval was selected, based on the quality of the available water quality data base. In the Seneca Basin, the 17 month NURP intensive storm monitoring effort conducted at Dawsonville, Md., represented the most complete dataset with which

to compare to simulated values. Therefore, the calibration interval extended from the August 1, 1980 to December 31, 1981 period covered by that dataset.

2. Observed water quality data was reduced to a level where it could be directly compared to model outputs. In the Seneca application this involved transforming the monitored data collected from NURP into cumulative and individual storm event mass loadings for each water quality constituent.

3. An initial estimation of model parameters was then made. This step necessitated the review of all the pertinent information in Seneca Creek and adjacent watersheds which related to watershed and stream characteristics. From this body of data (much of which can be found in Vol. II) initial parameters sets were constructed.

4. The model was subsequently executed and observed and simulated cumulative mass loadings were compared. Calibration efforts began with simulation of water quality loadings from the land surface. When a reasonable correspondence had been reached with stream quality data, calibration of the instream dynamics was initiated. Calibration of each water quality constituent followed a prescribed hierarchial sequence. For example, sediment erosion and instream sediment dynamics could not be calibrated until the watershed hydrology was successfully calculated. Watershed loadings of quality constituents were calibrated next, followed in turn by the instream DO budgets and nutrient transformations.

5. The initial paramater sets were then incrementally adjusted to further minimize the difference between observed and simulated data sets. In this application, calibration included a comparison of the following data sets:

   a) Approximately 45 instantaneous baseflow concentration samples.

   b) Approximately 25 individual storm event mass loads.

   c) Estimated cumulative 17 month loads for each constituent.

   d) Three months of daily summer DO concentrations.

The calibration process was continued until a good level of correspondence was reached between model simulations and observed water quality data. As defined by Anderson Nichols (1982), good correspondence between observed and simulated values occurs when there is agreement with 10 percent for hydrology, 15 percent for sediment, and 20 percent for nitrate and dissolved oxygen, on a annual or monthly basis.

PERFORMANCE OF THE SENECA CREEK MODEL

Simulation of Basin Hydrology

Several of the comparative graphics used to evaluate the adequacy of the calibratoin/verification of the runoff component of the Seneca Creek model are presented in Figures 3.4 through 3.7.

The first test of the model involved a nine year comparison of observed and simulated runoff volumes recorded at Dawsonville, Md. (Figure 3.4). This plot shows that the model is capable of adequately simulating annual runoff volumes in both dry and wet years. The mean error in projecting annual runoff volumes over the calibration and verification intervals was less than 10 percent.

A second comparative measure used to assess the model's ability to project runoff is presented in Figure 3.5. This graph, termed a one-to-one plot, compares observed and simulated ruoff volumes at monthly intervals. Each point on the graph represents a pair of observed and simulated runoff volumes, and the points proximity to the line of equal values serves as an indication of the accuracy of the simulation effort (the line of equal values is where observed monthly runoff volumes are equal to simulated runoff valomes). The clustering of points around this line in Figure 3.5 provides evidence that the model is capable of accurately simulating monthly runoff volumes.

A third test of the model is illustrated in Figure 3.6, which is a comparison of observed and simulated mean daily discharge values during 1970. The top panel depicts the observed discharge record projected by the model over the same interval. As can be seen, there is generally an excellent correspondence between both panels during most times of the year. The majority of the storms in the observed discharge record are reproduced, and the seasonal changes in baseflow levels are duplicated.

An additional method for assessing the success of the hydrology calibration/verification is flow duration analysis. Discharge levels are plotted on the x-axis, and the cumulative frequency with which a given discharge level is exceeded is plotted as a percentage on the y-axis. This procedure enables one to gauge how well the model simulates runoff over the entire spectrum of flow conditions, relative to existing conditions. Figure 3.7 depicts the results of comparative flow durations during the five-year verification interval. Each curve was constructed using over 1800 different daily flow levels. As can be seen, the observed and simulated flow duration curves virtually over plot, indicating that the model successfully simulates the observed frequency of flow events.

The complete results of the calibration and verification of the hydrology model can be found in the Technical Paper C contained in Volume II. The conclusion reached in the report was that the HSPF Model satisfactorily simulated runoff on an annual, monthly, daily and individual storm event basis during both the four year calibration interval and the five-year verification interval. As a result, the hydrology component of the model was considered to be successfully calibrated and verified.

Figure 3.4
Comparison of Observed and Simulated
Annual Runoff Volumes Recorded at Dawsonville:
1967-1975.

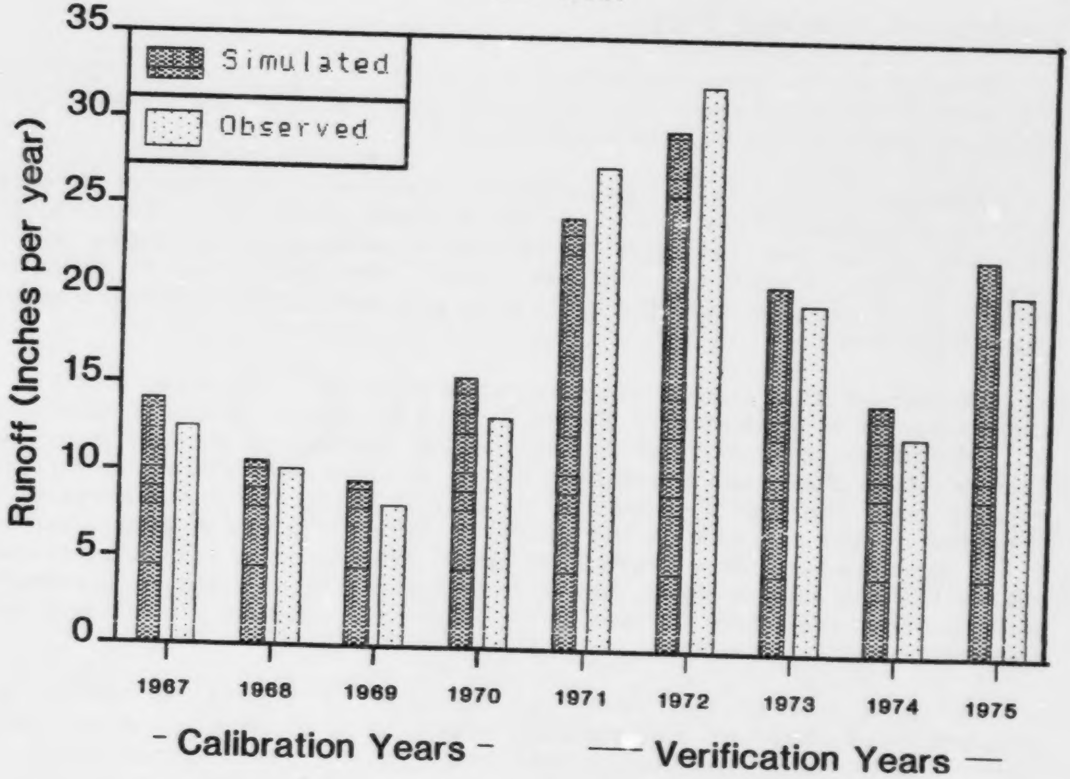


Figure 3.5
A Comparison of Observed and Simulated
Monthly Water Yields at Dawsonville:
1967-1975

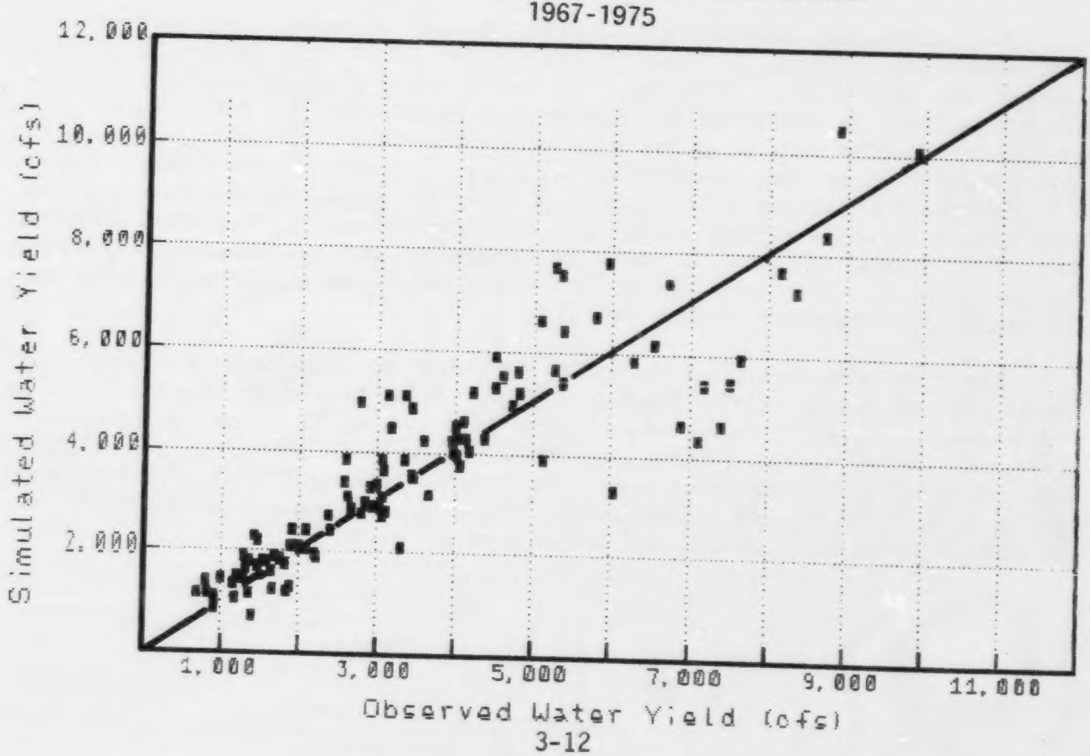


Figure 3.6

Comparison of Observed and Simulated Mean Daily Discharge at Dawsonville: 1970

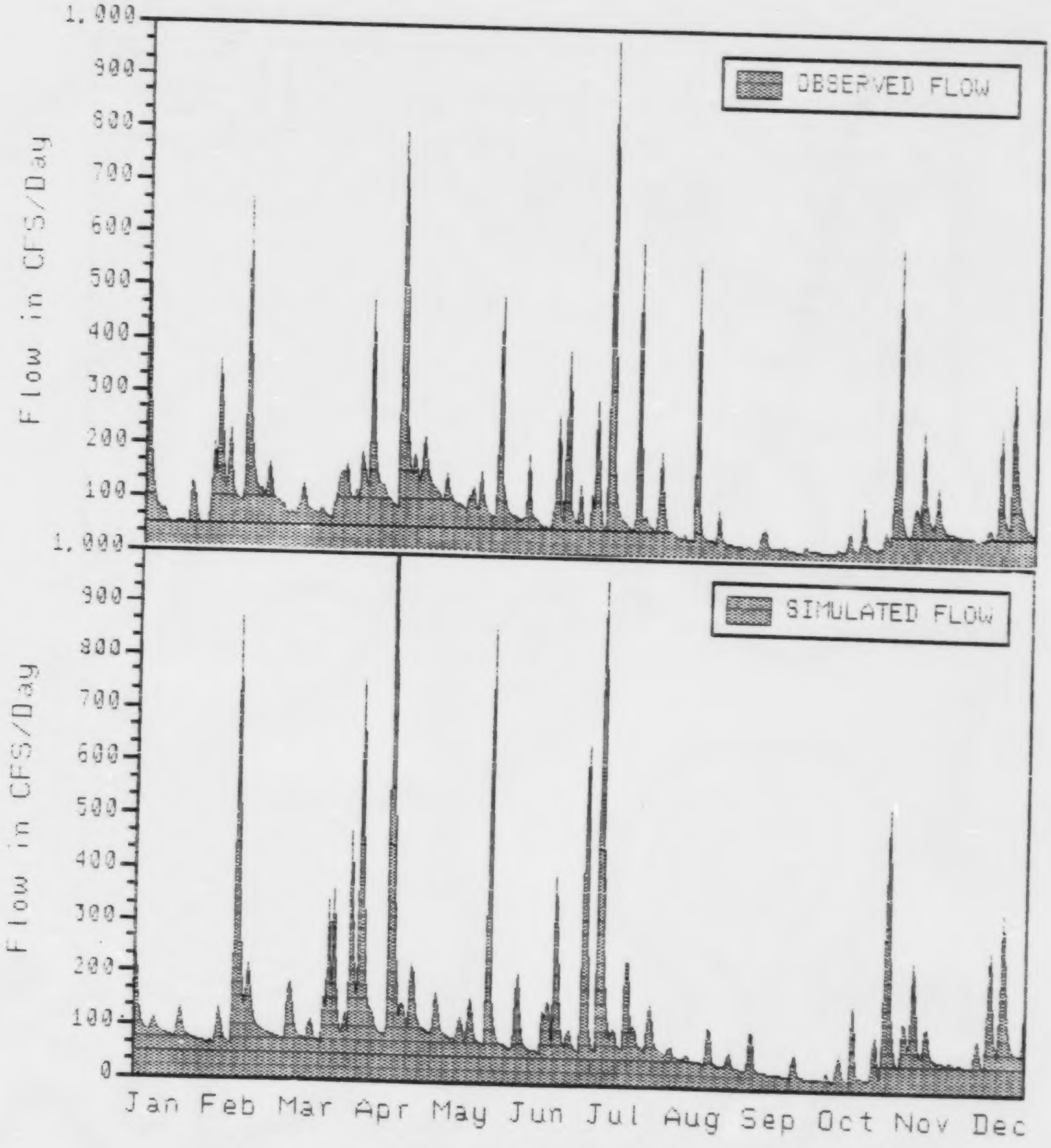
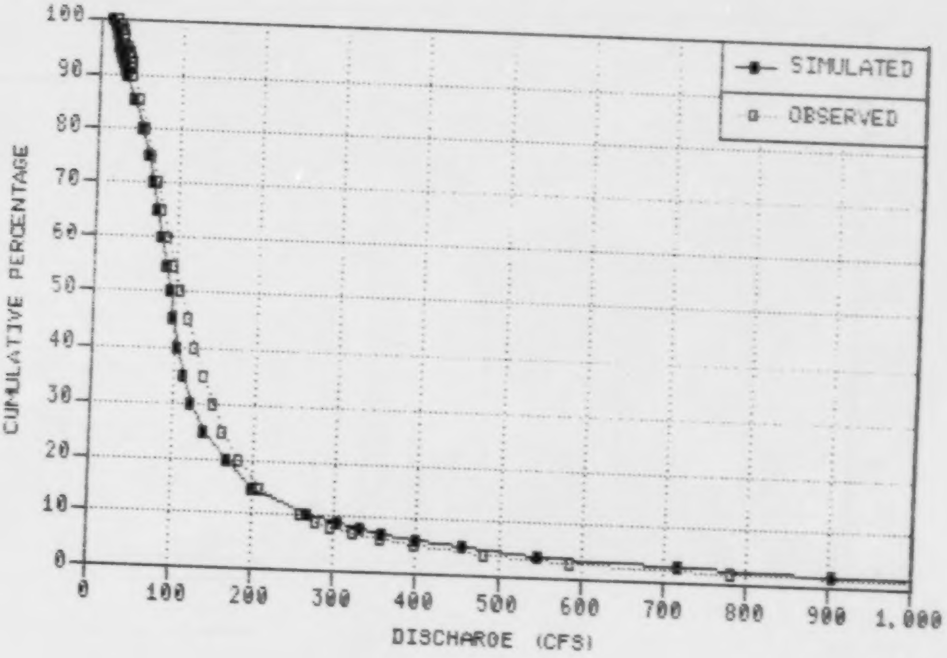


Figure 3.7

Seneca Creek Flow Duration Analysis:
Verification Interval 1971-1975



Simulation of Instream Water Quality

Table 3.3 highlights some of the major results of the water quality calibration. As can be seen, the observed and simulated cumulative mass loadings for the six water quality parameters are very similar. The difference in mass loads during the 17 month NURP monitoring study was +3 percent for sediment, +1 percent for total phosphorus, +2.5 percent for nitrate-N, +12 percent for organic nitrogen and 10 percent for ammonia. Table 3.3 also presents the correlation coefficients (r2) that were derived when linear regression techniques were applied to the distributions of observed and simulated mass loadings for individual storms. The excellent correlation values for all of the water quality parameters suggest that the Seneca model realistically portrays instream water quality. Some indication of this can be discussed in the one-to-one plots of sediment and phosphorus (Figure 3.8 and Figure 3.9). The close proximity of most of the points to the lines of equal values provides evidence that the model is very capable of simulating this sediment and phosphorus loads in the stream. Similar plots for the other water quality parameters can be found in the water quality calibration documentation report, located in Volume II of this report.

The ability of the model to continuously simulate instream dissolved oxygen levels is illustrated in Figure 3.10. This plot compares the observed daily range in dissolved oxygen concentrations with the daily mean concentration derived by the model, over a three month period in the critical summer months. In general, the simulated mean tracks the observed range very closely throughout most of the summer, with only a few exceptions.

Table 3.3

Performance of the Seneca Creek Watershed Model

Water Quality Constituent	Units	Cumulative Load		Pearson Correlation Coefficient
		Observed	Simulated	
Sediment	tons	17,500	18,050	0.97
Total P	lbs	44,200	49,900	0.96
Nitrate-N	lbs	561,000	575,000	0.90
Organic-N	lbs	152,000	170,000	0.91
Ammonia	lbs	19,240	21,130	0.93
Dissolved oxygen	mg/l	—	—	0.89

Figure 3.8 Observed and Simulated Storm Sediment Yields at Dawsonville, 1980-1981

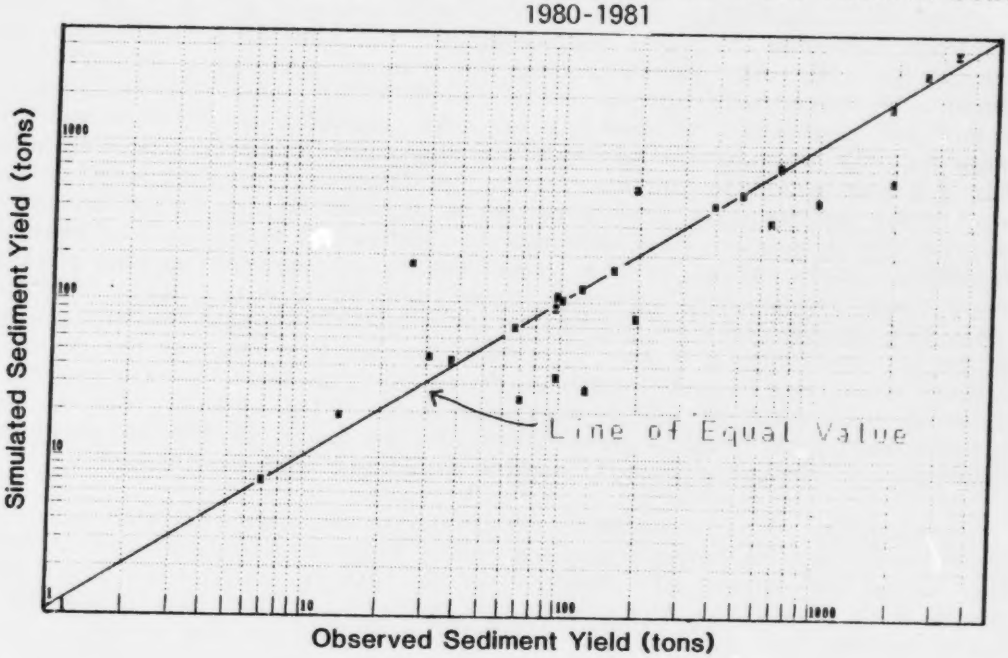


Figure 3.9 Observed and Simulated Storm Total Phosphorus Yields 1980-1981

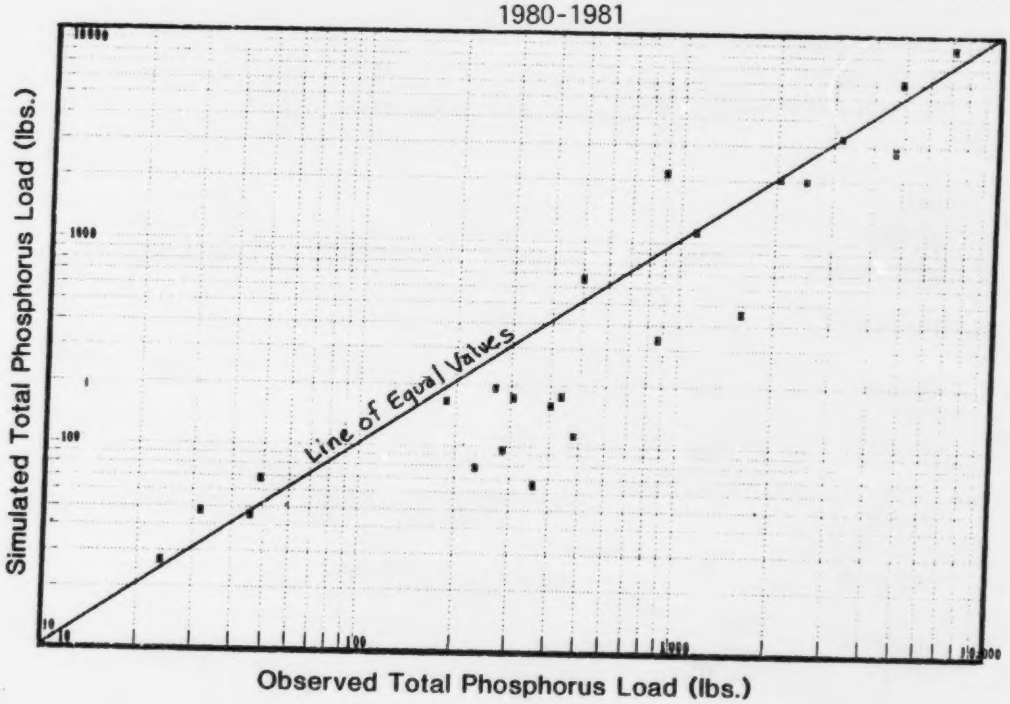
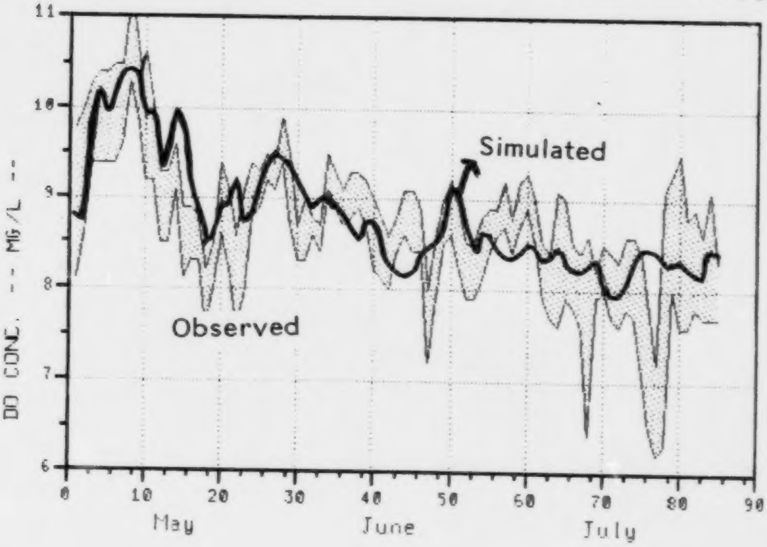


Figure 3.10

Continious Simulation of Instream Dissolved Oxygen



SUMMARY: PERFORMANCE OF SENECA CREEK MODEL

The water quality component of the Seneca model was subjected to a hierarchial series of tests to evaluate its ability to reproduce the behavior of water quality constituents within the stream. These tests included graphical and statistical comparisons of observed and simulated cumulative mass loadings, storm event mass loadings, and baseflow comparisons. In all cases, the model was found to be capable of reasonably approximating instream conditions within Seneca Creek, as they were observed at Riffleford Road and Dawsonville, Md. As a result, the model is considered to be successfully calibrated for use as a water quality management tool. This achievement sets the stage for further application of the model to evaluate the water quality response of the impacts of future development on water quality within the basin.

Chapter Four

PROJECTED WATER QUALITY FOR THE SENECA CREEK WATERSHED

PROJECTED WATER QUALITY FOR THE SENECA CREEK WATERSHED

After the Seneca Creek watershed model had been calibrated to 1980-1981 water quality conditions, it was applied to project nonpoint loads under past, present and future land use patterns in the watershed. This was accomplished by redefining the distribution of land use within model to reflect the desired land use pattern. Three such model runs were made. The first was the PRISTINE land use condition, which assumed an undeveloped watershed with full forest cover. The PRISTINE condition was used to provide a baseline, or natural background level, from which the water quality and quantity effects of both present and future levels of development could be assessed.

The second model run simulated EXISTING conditions within the watershed, and was based on the prevailing land use patterns in 1980. During this period, about 16 percent of the basin was developed, 46 percent was devoted to crop or pastureland, and 38 percent was forest or grassland (Figure 4.1).

The final model run, ULTIMATE, was configured to reflect the anticipated land use distribution when the basin is fully developed, as specified in the 1975 Functional Master Plan (M-NCPPC, 1977). In this scenario, much of the land presently devoted to open space would be converted to more suburban uses (Figure 4.1). Specifically, only 13 percent of the basin would be retained as grass or forest land, 28 percent would be in crops and pasture and 59 percent would be developed. Most of the development (60+ percent) is planned to be of the low density residential variety (i.e., 0.5 to 5 dwelling units per acre).

Assumptions Underlying Projections

The model generated projections of water quality conditions are compared in Table 4.1. All projections were made assuming a year of average precipitation and no controls. The ULTIMATE model run further assumed that future municipal sewage treatment plant discharges would not change from EXISTING conditions. Two additional notes about the projections are necessary. First, none of the projections explicitly considered the trapping effects of Little Seneca Lake, presently under construction. Since the Lake has been estimated to have a 99 percent trap efficiency for sediments (Black and Veatch, 1980), it can be expected that the delivery of particulate pollutants below the reservoir would be substantially curtailed. As the drainage area upstream of the reservoir represents about 20 percent of the Seneca Basin (draining to Dawsonville), the reduction in downstream projected loads could conceivably be of the same order. Secondly, it should be noted that the projections encompass only the 101 square mile draining to Dawsonville, and that a portion of the extreme western part of the watershed was not explicitly modeled. This predominately rural area, representing about 20 square miles (or 20 percent of the total watershed area) is expected to remain in its relatively undeveloped state over the next twenty years.

Basin-wide Water Quality Projections

The model generated projections of Seneca Creek water quality conditions are compared in Table 4.1. The water quality and quantity impacts associated with the land use projections have been grouped into four general categories: flow related impacts, sediment related impacts, nonpoint pollutant loads and oxygen related impacts.

Figure 4.1 Existing and Ultimate Land Use Distributions in Seneca Creek Watershed

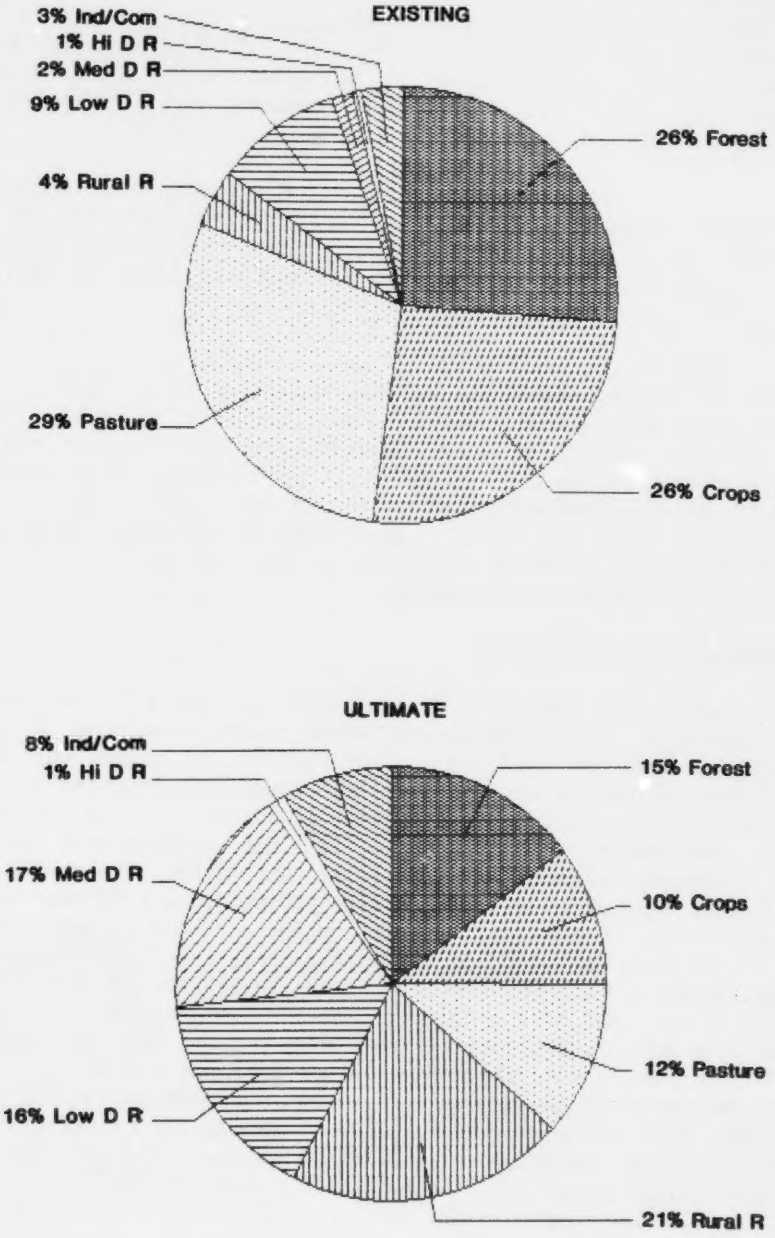


Table 4.1

Past, Present and Future Water Quality Conditions in Seneca Creek Projected by the Basin Model [a]

		LAND USE SCENARIOS [b]		
FLOW RELATED IMPACTS	UNITS	PRISTINE	EXISTING	ULTIMATE
PEAK DISCHARGE	cfs	2,530	2,935	3,550
RUNOFF VOLUME	cfsd	79	96	117
SUMMER LOW FLOW	cfs	32	29	27
SEDIMENT RELATED IMPACTS				
TOTAL SEDIMENT YIELD	tons	12,230	60,560	75,910
STREAM BANK EROSION	tons	6,011	8,515	18,620
CHANNEL DEPOSITION	tons	2,970	25,500	25,400
SUSPENDED SEDIMENT	days>100mg/l	13	63	76
EXCEEDANCE FREQUENCY	days>300mg/l	7	29	43
NON POINT SOURCE LOADS				
NITRATE-N	lbs	140,800[c]	475,200	530,000
AMMONIA-N	lbs	20,480[c]	34,800	27,930
TOTAL ORGANIC-N	lbs	160,000	670,450	774,680
TOTAL-N	lbs	321,300	1,180,450	1,332,610
TOTAL-P	lbs	16,180	65,070	78,800
OXYGEN RELATED				
MINIMUM DISSOLVED OXYGEN (DO)	mg/l	6.1	6.0	5.6

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[a] For year of TYPICAL Precipitation (1970 -42 inches)

[b] Effect of Little Seneca Lake (i.e., sediment trapping) not considered

[c] estimated from loading data only; no nitrification processes considered.

Flow Related Impacts

As might be expected, the flow regime in Seneca Creek simulated under the PRISTINE condition was much more stable than either the EXISTING or ULTIMATE condition. The forested areas sustained a high dry weather flow condition, and retained more precipitation in watershed soil and vegetation (this is suggested by the fact that the PRISTINE condition produced only 80 percent of the annual runoff experienced under the EXISTING condition). Consequently, the peak runoff from large storm events were well moderated.

The EXISTING land use condition exhibited flow regimes that were moderately altered from the natural background. Summer low flows were reduced by approximately 3 cfs, while peak runoff discharges increased by 16 percent, and the cumulative runoff volume rose by nearly 20 percent, relative to the PRISTINE condition.

Flow regimes were much more variable and unstable under the ULTIMATE land use condition. Because of the high degree of basin imperviousness (21 percent), less water infiltrated into the soil and more runoff was directly routed to the channel. As a result, peak runoff discharges increased by 21 and 41 percent, over the EXISTING and PRISTINE conditions, respectively. The increase in annual runoff volume was also of the same order. The ULTIMATE condition also was not projected to sustain dry weather baseflow at EXISTING levels.

Sediment Related Impacts

The EXISTING sediment yield at Dawsonville is nearly five times higher than the yield that would be expected from a completely reforested watershed. The majority of the EXISTING sediment yield is derived from soil erosion from crop and pasture areas. One consequence of the EXISTING sediment yield is that high suspended sediment concentrations are a relatively frequent occurence in the stream.

The simulated sediment yield delivered under the ULTIMATE land use condition was nearly 25 percent higher than the EXISTING condition, and 6 times higher than the PRISTINE condition. Much of the projected increase in sediment yield in the ULTIMATE scenario can be attributed to dramatic increases in streambank erosion, which is nearly 200 percent greater than the existing scenario. The number of days of Seneca Creek was projected to have elevated suspended sediment concentrations increased substantially over the EXISTING condition. Of particular concern was the projected increase of nearly 50 percent in the frequency of extremely high (>300 mg/l) sediment concentrations in the stream. Taken together, the sediment impacts of the ULTIMATE plan suggest, that in the absence of any control measures, aquatic habitat in Seneca Creek will undergo significant deterioration.

Nonpoint Source Loads

The nutrient load delivered to the Dawsonville gauging station was projected to increase moderately under the fully developed ULTIMATE scenario. Total nitrogen loads were expected to rise by 13 percent, and total phosphorus loads by nearly 20 percent, relative to existing conditions. The increase in future nutrient loads was partially off-set by declines in total agricultural nutrient loadings. However, the conversion of forested and grassed areas, (which have very low nutrient loads, indicated by the

PRISTINE condition) to suburban development (with have moderate nutrient loadings) resulted in the overall projected increase.

As a consequence of the increased nutrient loadings, the potential for eutrophication in impounded waters within the Seneca watershed, noted in the Technical Paper A, will be increased. Increases in nutrient loadings in Seneca Creek, and eventually exported to the Potomac River are also estimated to be greater under the ULTIMATE scenario. Preliminary comparisons with nutrient loadings predicted by Chesapeake Bay Basin Model (Hartigan, 1982) suggest that the total Seneca Creek nutrient loads associated with the ULTIMATE condition could raise the total nutrient load to the Upper Potomac Estuary by 1 to 2 percent (in an average year of precipitation).

Oxygen Related Impacts

Although the total quantity of oxygen demanding materials generated under the ULTIMATE condition was projected to increase substantially, the effect on oxygen dynamics within Seneca Creek are projected to only be marginal. The minimum dissolved oxygen concentration experienced throughout the mainstem of Seneca Creek was projected to decline by 0.5 mg/l. To put this change in proper perspective, the typical daily fluctuation in dissolved oxygen recorded at Riffleford Road is about 2.0 mg/l (DEP, 1981). No violations of the Maryland State Standard of 5.0 mg/l were projected to occur under the ULTIMATE condition. This is not surprising, since Seneca Creek is generally a fast moving, shaded and well aerated stream.

Summary

The water quality projections generated by the Seneca Creek Model suggest several important conclusions. First, the comparisons of water quality conditions between the PRISTINE and EXISTING land use conditions underline the fact that present conditions in Seneca Creek have substantially deteriorated from what they once were. The stream now has higher peak runoff discharges, lower dry weather stream flow, and is generally more turbid. As a result, the quality of stream habitat has declined, as reflected in the historical fish diversity data in Technical Paper A. Also, the loads of sediments, nutrients and oxygen demanding materials conveyed in Seneca Creek has climbed considerably since the area was originally settled.

Secondly, the expected levels of future development were projected to continue this negative trend in water quality, in the absence of any controls. Of particular concern are projected increases in stormwater runoff, streambank erosion and turbidity levels. The specific impacts associated with the ULTIMATE land use condition vary considerably throughout Seneca Creek. In general, the severity of these impacts is greatest nearest the rapidly urbanizing corridor cities, such as Clarksburg, Germantown and Gaithersburg.

Chapter Five

SPECIAL MODELING STUDIES IN THE CLARKSBURG PLANNING AREA

SPECIAL MODELING STUDIES IN THE CLARKSBURG PLANNING AREA

At the request of M-NCPPC staff, MWCOG developed a more detailed version of the Seneca Creek Watershed model in order to assess the relative water quality and stream habitat impacts of seven land scenarios in the Clarksburg Planning Area. This more detailed version, termed the Little Seneca sub-model, is identical to the Seneca Creek Model in most respects. The channel system, however, was expanded to represent the three major tributaries to Little Seneca Lake. This section presents the results of the initial series of model applications which project water quality and quantity impacts based solely on land use distribution alone (i.e., no stormwater or nonpoint source controls were utilized).

Description of the Clarksburg Planning Area

The 20 square mile Little Seneca watershed is located approximately 25 miles to the northwest of Washington, D.C., in the rolling foothills of the Maryland piedmont (Figure 5.1). Slopes are typically moderate to steep, with elevations ranging from 400 to 700 ft. above sea level. The well drained silt loam soils that are predominant in the watershed support a great deal of agricultural production, with row crops and pasture occupying 57 percent of the watershed. Forest is the other principal land use taking up 30 percent of the area. The three main tributaries to the reservoir are Little Seneca Creek, Cabin Branch, and Ten Mile Creek.

The Clarksburg Planning area was selected for special attention for several reasons. First, the current master plan forecasts that much of the rural Clarksburg area will undergo substantial development over the next twenty years. As a result, the significant changes in the quality and quantity of surface waters can be expected. The planning area, which encompasses much of the Little Seneca watershed, also contains several unique aquatic resources. These include one of the most diverse fish communities within the County, and the only Class IV, recreational trout waters in the Seneca watershed. The planning area also represents almost the entire upland drainage to the Little Seneca reservoir. Finally, the M-NCPPC master planning process is still in its early stages in the Clarksburg Planning Area. It was felt that this study could provide relevant information on likely changes in water quality and stream habitat associated with land use options for timely incorporation into the master planning process.

Table 5.1 General Features of MNCPPC Land Use Options in the Clarksburg Planning Area

Land Use Planning Alternatives

Pristine: Predevelopment (100% forest cover)

Existing: 1980 land use (14% developed)

Ultimate: Outdated master plan (90% dev.)

Master Plan Alternatives

Maximum: Maximum development option (60%)

Option A: Downzoning to rural residential and open space

Option B: Downzoning to open space/agricultural preservation

Option C: Option A with a high tech industrial corridor

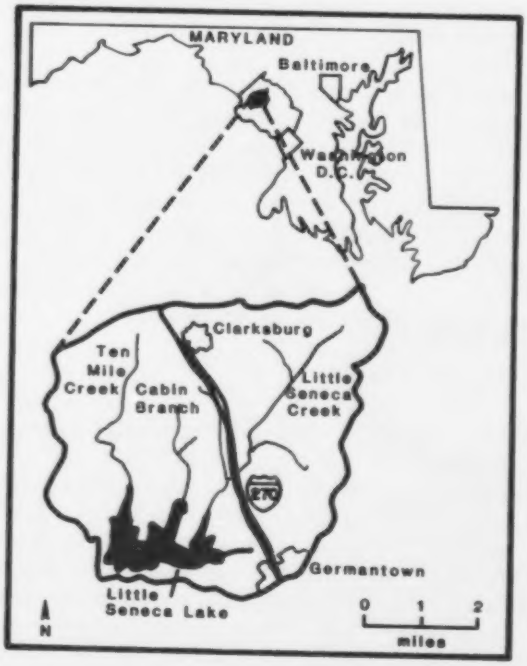
LAND USE SCENARIO	FOREST	AGRICULTURAL	DEVELOPED	IMPERVIOUS
		%		
Existing	28.9	56.7	14.3	5.2
Maximum	9.5	29.3	61.2	20.0
Maximum/Option A (Pasture and RR)	3.9	41.9	54.2	17.9
Maximum/Option B (Pasture Only)	6.7	47.0	46.3	16.9
Maximum/Option C Expanded Industrial	3.8	38.5	58.5	21.2
Ultimate	5.2	3.6	91.5	26.7

DESCRIPTION OF FUTURE LAND USE ALTERNATIVES

As can be seen in Table 5.1, all of the future land use scenarios under consideration by the M-NCPPC staff for the Clarksburg Planning Area would involve substantial conversion of rural lands to suburban development (M-NCPPC, 1983). The MAXIMUM plan option would entail the development of approximately 60 percent of the watershed draining to Little Seneca Lake. The other three planning options under active consideration are all offshoots of the MAXIMUM plan. OPTION A calls for the downzoning of the area of the watershed below Interstate 270 to rural residential and agricultural uses (Figure 1). In the OPTION B plan, the same area is exclusively zoned to agricultural uses. The last maximum scenario, OPTION C, is similar in most respects to OPTION A, but also involves the development of an industrial corridor west of I-270. The current adopted master plan, which calls for varying degrees of development in 90 percent of the watershed, is represented by the ULTIMATE land use scenario. A complete discussion of the characteristics of each land use planning alternatives can be found in Technical Paper B in Volume II.

For the sake of comparison, a "pre-development" or PRISTINE watershed alternative was also included with the results. Pre-development in this case represents full forest cover over the entire basin, and was used to estimate the level of natural background water quality and hydrology in the basin, so as to provide a benchmark with which to assess the relative impacts of the M-NCPPC land use scenarios. The EXISTING land use pattern was also simulated as a reference.

Figure 5.1 Location of the Little Seneca Watershed



IMPACTS OF LITTLE SENECA LAKE

All of the M-NCPPC land use planning options were simulated by the Clarksburg model utilizing a normal year of rainfall to determine their relative effects on the water quality of Little Seneca Lake. To develop a "worst case" comparison, the model simulations initially assumed that no stormwater or nonpoint source control programs would be in effect in the future. As in the previous chapter, this assumption was undertaken to isolate the direct impacts of each of the land use planning measures. Subsequent model simulations examined the relative impacts of selected agricultural and urban control strategies, and these are described in Chapter 6.

Algal Levels in Little Seneca Lake

Chlorophyll "a" is a plant pigment which is utilized in the process of photosynthesis. Easily measured, it is often used to estimate algal levels, and to indicate the degree of eutrophication or nutrient enrichment of a water body. Chlorophyll "a" levels above 20 micrograms per liter can be expected to induce eutrophic conditions in lakes (NVPDC, 1982). These conditions are often characterized by blooms of nuisance algal, dissolved oxygen deficits, odor problems and diminished water clarity. In extreme cases, eutrophic conditions can result in fish kills.

Functional relationships originally developed by Vollenwieder (1977) were used to estimate future chlorophyll "a" levels in Little Seneca Lake. These relationships are based on reservoir geometry, hydraulics and phosphorus loading rates, and were verified to conditions in the nearby Occoquan reservoir. The equations predicted mean annual chlorophyll "a" levels to within 15 percent of observed conditions. Once the regional validity of the Vollenwieder relationship had been established, the equations were recomputed using the projected phosphorus loading data in each land use scenario, coupled with the appropriate hydraulic and geometrical parameters (derived from Black and Veatch, 1979).

Simulations of total phosphorus loads generated by all of the future land use scenarios, including the existing situation, were estimated to produce mean annual chlorophyll "a" levels in excess of 25 micrograms per liter (Figure 5.2). By way of contrast, the PRISTINE land use condition, which assumed a full forest cover over the entire watershed, was projected to have mean annual chlorophyll "a" levels of 6 micrograms per liter, a non-eutrophic condition. To prevent the occurrence of the eutrophic conditions associated with future development, it was estimated that total phosphorus inputs to the lake would need to be reduced by 45 to 55 percent.

Sediment Loads to Little Seneca Lake

Projected sediment loads to the lake did not vary substantially among the six land use scenarios, with reductions in sediment yield from agricultural areas typically being offset by increased streambank erosion projected from areas of more intense development. OPTIONS A, B, and C were projected to deliver higher sediment loads to the lake than the EXISTING, MAXIMUM and ULTIMATE scenarios (Table 5.2). During an average year of rainfall, approximately 15 to 20 acre-feet of sediment would be delivered to the Lake under all of the future scenarios. Assuming that 35 percent of this sediment is trapped in the forebays before reaching the lake

Figure 5.2 Projected Mean Annual Chlorophyll "a" Levels in Little Seneca Lake: Future Land Use Alternatives

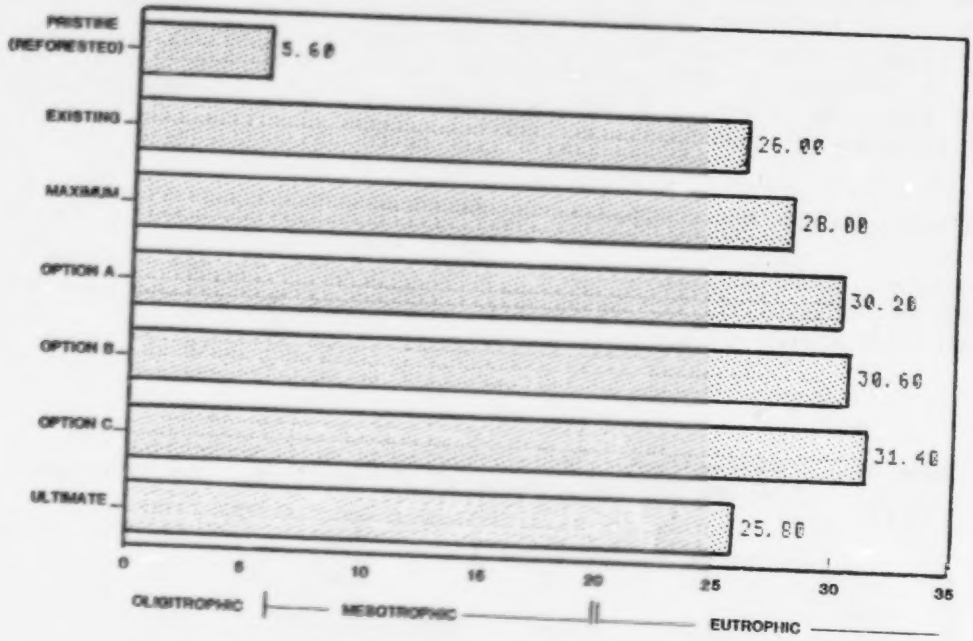
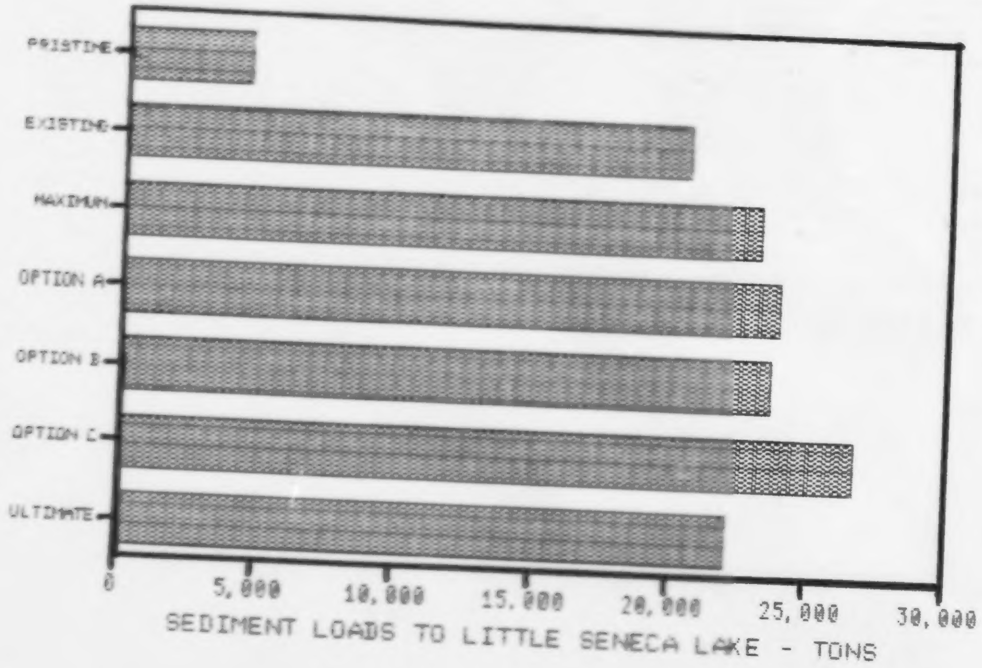


Figure 5.3 Projected Sediment Input to Little Seneca Lake Under Future Land Use Scenarios



(Black and Veatch, 1979), between 3 and 4 million gallons of storage capacity in the reservoir would be lost annually (or approximately 975-1000 acre-feet of storage over the 100 year life of the project). Also, it is estimated that the 108 acre-feet storage capacity of the sediment forebays would be completely filled within 16 to 21 years. The estimated annual cost of dredging these sediments from the forebay alone range from $42,000 to $56,000, based on the dredging and disposal costs cited in Black and Veatch (1979). In addition to the reductions in forebay and reservoir storage capacity, the model projections indicate that the arms of the lake will most likely experience highly turbid conditions immediately after large storm events.

Loads of Nitrogen and Oxygen Demanding Materials to the Lake

Projected loads of nitrogen delivered to Little Seneca Lake were projected to increase by 10 to 50 percent, depending on the land use scenario (Table 5.2).

Table 5.2 Future Water Quality and Quantity Projections for Clarksburg Planning Area Alternatives: No Controls

		LAND USE SCENARIOS						
	UNITS	PRISTINE	EXISTING	ULTIMATE	MAXIMUM	OPTION A	OPTION B	OPTION C
FLOW RELATED IMPACTS[b]								
Peak Discharge	cfs	1,295	1,400	1,947	1,885	1,775	1,562	1,865
Runoff Volume	cfsd	17.0	20.1	27.8	26.2	24.8	24.2	26.5
Dry Weather Low Flow	cfs	5.8	5.5	4.4	5.0	4.9	5.0	4.6
Maximum Water Velocity[a]	ft/sec	--	3.05	3.75	3.62	3.46	3.33	3.87
SEDIMENT RELATED IMPACTS[b]								
Total Sediment Yield	tons	4.480	20.500	22.130	23,100	23.900	23.600	26,700
Stream Bank Erosion	tons/mi/yr	80	115	248	218	189	160	243
Channel Deposition	tons	13	122	83	106	124	126	115
Suspended Sediment	days>100mg/l	21	40	51	48	45	45	51
Exceedance Frequency	days>300mg/l	7	23	31	29	27	27	31
NONPOINT SOURCE LOADS[b]								
Nitrate-N	10^3lbs	34.5	86.5	90.7	91.8	95.6	94.6	98.3
Ammonia-N	10^3lbs	5.5	11.2	4.9	8.0	9.7	10.2	9.3
Organic-N	10^3lbs	35.6	124.6	149.6	163.0	176.1	177.7	181.5
Total-N	10^3lbs	4.0	221.0	243.0	262.0	281.0	287.0	311.0
Total-P	10^3lbs	2.99	14.5	14.6	15.8	17.1	17.2	17.6
OXYGEN RELATED[b]								
BOD, five day	10^3lbs	336.0	810	1,083	1,098	1,069	1,044	1,186
Minimum DO	mg/l	7.0	6.8	6.65	6.8	6.8	6.7	6.8

NOTE: All projections assume that no stormwater or nonpoint source controls are operating in the Clarksburg Planning Area.

a. Mean of Monthly Maxima in Ten Mile Creek.
b. Average Year of Precipitation.

PROJECTED IMPACTS ON LITTLE SENECA LAKE TRIBUTARIES

Impacts of future development on the habitat of tributary streams were assessed by examining the effects of each scenario on key physical factors that tend to produce stress in the aquatic environment. These factors included volume of stormwater discharge, streamflow during extended dry periods, maximum water velocities, streambank erosion, channel deposition of sediments, and suspended sediment and minimum dissolved oxygen concentrations. As in the previous section, all model projections assumed that no control measures would be in place.

Dissolved Oxygen

Minimum dissolved oxygen concentrations predicted by the model, in all cases, were consistently above the state standards.

Stormwater Runoff and Dry Weather Flows

Stormwater volumes increased substantially under all of the future scenarios -- from 22 percent in the OPTION B plan to 39 percent in ULTIMATE scenario (Figure 5.4). Also, peak stormwater runoff discharges were projected to increase by 20 to 40 percent. Conversely, flows during extended dry periods are projected to decrease by 10 (OPTION B) to 25 percent (ULTIMATE) in future scenarios. The general relationship seems to be that increased imperviousness leads to wide fluctuations in flow regimes, with the attendant adverse impacts on stream habitat.

Water Velocity and Streambank Erosion

Increases in maximum water velocities from 7 percent (OPTION B) to 23 percent (ULTIMATE) were observed in the future scenarios (Table 5.2). As a result, projected streambank erosion rates in the future scenarios increased significantly over the 115 tons/mile/per year average predicted for the EXISTING land use. As can be seen in Figure 5.5, the rate of streambank erosion doubles in the most intensively developed land use scenarios (such as OPTION C and ULTIMATE). Besides the obvious effects on downstream sediment loadings, streambank erosion rates of this magnitude could seriously affect riparian habitat in the Class IV trout streams, as well as creating a wider and more shallow channel.

Suspended Sediment Concentrations

Suspended sediment levels were projected to exceed 100 mg/l approximately 45 to 51 days a year under all the future master plan options analyzed. This compares to a 40-day frequency projected for existing land uses and a 21 day frequency under PRISTINE conditions. Thus, the number of days that tributary streams would experience high turbidity levels will rise by 13 to 28 percent. The 100 mg/l concentration is used here as a suggested threshold for protection of aquatic life, and roughly corresponds to the 150 JTU Maryland State Turbidity Standard (Figure 5.6).

Figure 5.4 Peak Discharge Levels Associated with Future Development in Clarksburg Planning Area

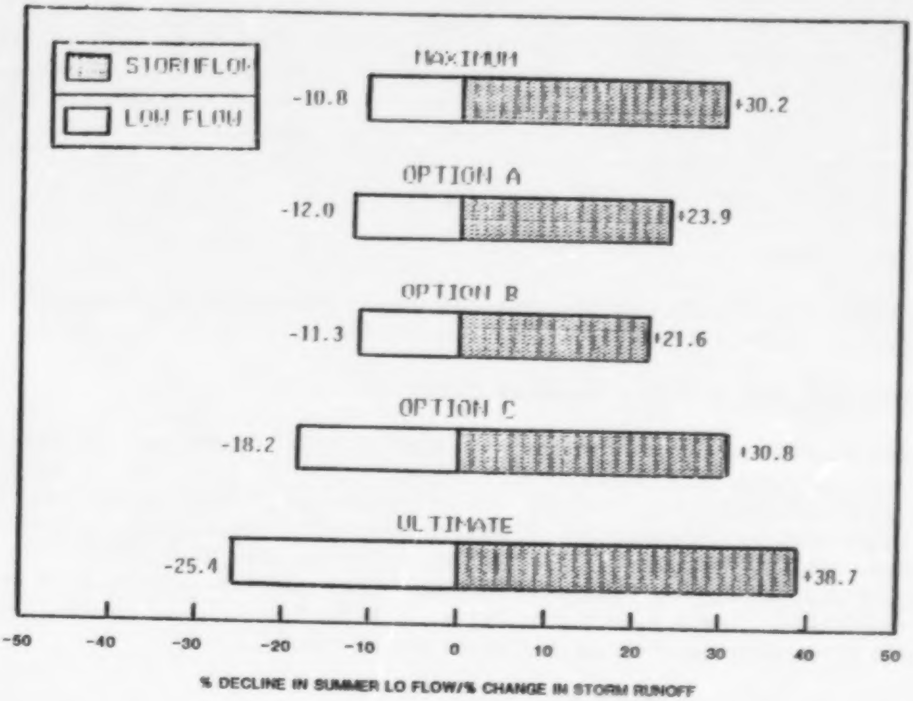


Figure 5.5 Projected Streambank Erosion Rates in the Clarksburg Planning Area Under Future Development Scenarios

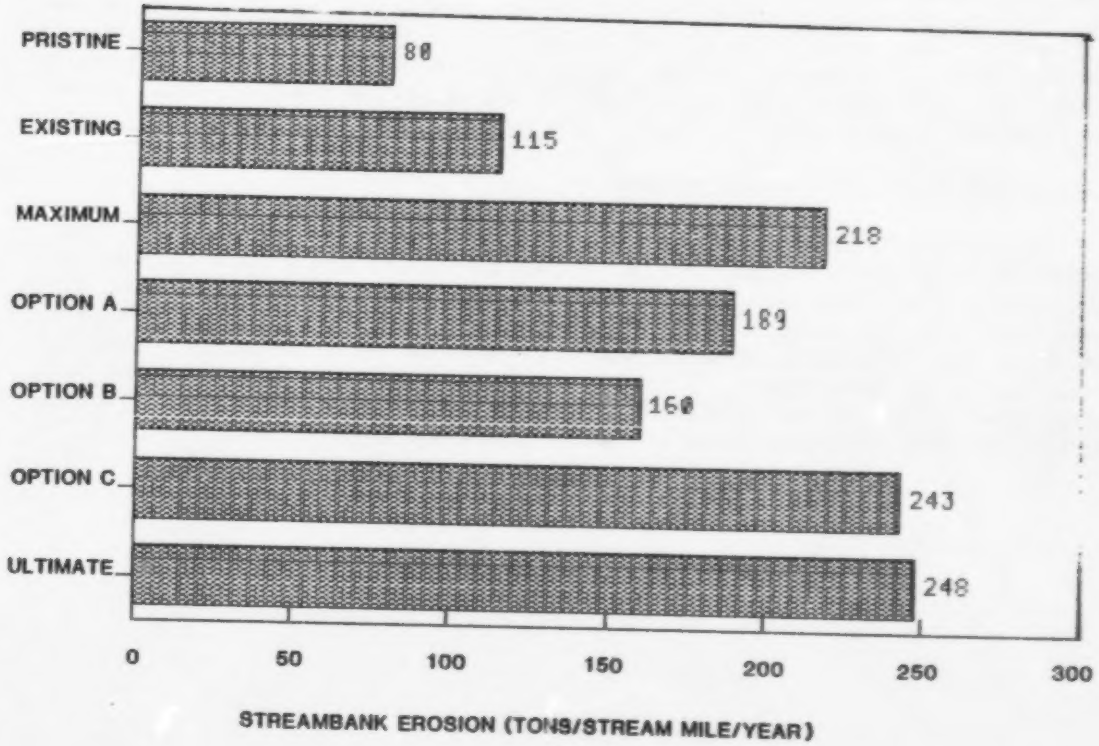
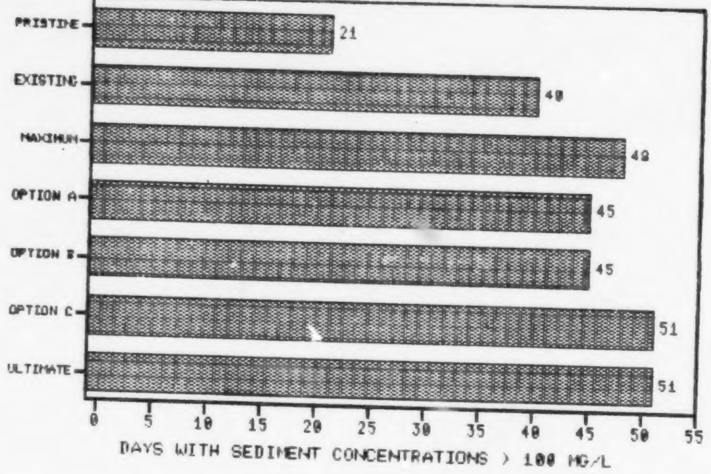


Figure 5.6 **Projected Duration of Elevated Suspended Sediment Concentrations in the Clarksburg Planning Area**



SUMMARY: PROJECTED EFFECTS OF FUTURE LAND USE ON WATER QUALITY IN CLARKSBURG

From the standpoint of the physical factors studied, it would appear that the OPTION A and OPTION B scenarios would afford the most protection for instream habitat, while the ULTIMATE, MAXIMUM and OPTION C scenarios would afford the least.

However, from the perspective of controlling nonpoint loads, model projections indicate that the OPTION A and OPTION B scenarios would deliver sediments, nutrients and oxygen demanding materials to the Lake in quantities which approach, and in some cases exceed, those delivered under more intensive development scenarios.

Finally, in the absence of any stormwater and nonpoint controls, all of the master planning land use options analyzed were projected to have highly deleterious effects on the water quality of Little Seneca Lake and the habitat of the Class IV streams which drain into it. Therefore, if the beneficial uses of either aquatic resource are to be maintained, then some kind of comprehensive watershed control program may be warranted in the Clarksburg Planning Area. Complete evaluations of the specific impacts to Little Seneca Lake and its tributaries associated with each planning alternative can be found in Technical Paper B, located in Volume II.

The next two chapters explore the projected effectiveness and cost of several basin-wide stormwater and nonpoint source control strategies which could be applied to maintain or improve future water quality.

Chapter Six

EFFECTIVENESS OF STORMWATER AND NONPOINT SOURCE CONTROL STRATEGIES

PROJECTED EFFECTIVENESS OF STORMWATER AND NONPOINT SOURCE CONTROL STRATEGIES

This chapter describes the results of a series of model production runs which evaluated the effectiveness of five hypothetical control programs in mitigating the water quality and quantity impacts of future development within the Clarksburg Planning Area.

In the first section, the major features of each of the five control strategies are detailed at some length. The process by which these strategies were incorporated into the context of the model is also discussed.

The second section focuses on the comparative results of the model projections for individual water quality indicators. These indicators include:

- Peak Discharge Levels.
- Summer Dry Weather Streamflow.
- Streambank Erosion Rates.
- Sediment Deposition Rates in the Channel.
- Exceedance Frequencies for Specific Suspended Sediment Levels in the Stream.
- Total Nitrogen, Phosphorus, Sediment and BOD Loads Delivered to Little Seneca lake.
- Simulated Mean Annual Clorophyll "a" Levels in the Lake.

In the third section, a simple indexing scheme is described which condenses the complex series of model projections into a more digestible format. This index is utilized as a broad screening tool to compare the overall effectiveness of the land use planning/control strategy combinations.

The final section provides a brief summary of the comparative effectiveness of the control strategies, and also identifies control strategies which could maintain or improve current water quality conditions.

ANALYSIS OF CONTROL STRATEGIES

After simulating the impacts of the various master planning alternatives without stormwater and nonpoint source controls the Clarksburg model was applied to evaluate the effectiveness of such controls in mitigating the adverse impacts of each scenario on lake water quality and stream habitat. A set of possible management strategies was identified for evaluation by the watershed model. Somewhat conceptual in nature, the management strategies reflect current practices, design criteria and nonpoint pollutant removal rates within the Washington region. They are intended to show a range of contrasting results from the "no-action" situation through maximum employment of best management practices.

Five management strategies were identified for further consideration. These included the basin-wide application of:

- Land use planning measures.
- Conventional "dry" stormwater ponds for peak runoff control.
- "Wet" stormwater ponds for peak runoff and nonpoint source control (including extended detention designs for highly impervious land uses).
- Comprehensive agricultural best management practices.
- A mixed program involving the application of wet ponds and agricultural BMPs.

The major characteristics of each of the control strategies are outlined in Table 6.1.

Land Use Planning Measures

The previous chapter highlighted the projected impacts of the different M-NCPPC planning options on stream habitat and lake water quality. The analysis assumed no stormwater or nonpoint source controls were in operation within the watershed. This rather unlikely assumption was undertaken to isolate the direct impact of the land use planning measure as a strategy for protecting water quality. In this chapter, further analysis is presented which illustrates the effects of land use planning measures in combination with the other agricultural and urban BMP control strategies.

Dry Pond Stormwater Controls

A "dry pond" stormwater management option was evaluated to represent the control practices currently required for new development under Montgomery County, Md. stormwater regulations. The principal element of these regulations is to provide volume and/or infiltration controls to the extent that the 2-year predevelopment peak discharge from a given area is not increased following development. The intent of this program is to reduce downstream flooding and streambank erosion.

Table 6.1 Major Features at Basin-wide Control Programs

Stormwater Management Scenario

- “Dry pond” detention basins
- Apply to 70% of new development
- Flow attenuation/peak shaving of two year storm
- Minimal removal of sediment and nonpoint source pollutants
- “Hardwired” into model
- Low and high density ponds

Urban BMP Scenario

- Use of wet ponds
- Provide stormwater plus nonpoint source control
- NPS removal rates based on NURP findings
- Applicable to 100% of all new development

Agricultural BMP Scenario

- Based on Little Seneca 566 Watershed Conservation Plan. (SCS)
- Involves cropland and animal waste management on 3100 acres, 8 dairy operations
  - — Conservation tillage
  - — Cover crops and crop residue retention
  - — Contour & strip farming
  - — Diversions and grassed waterways
  - — Animal waste collection systems
- Assumes load reduction projected by SCS

Mixed BMP Scenario

- Combination of application of agricultural and urban best management practices (wet ponds)
- Represents the maximum level of stormwater and nonpoint source control

TABLE 6.2

CHARACTERISTICS OF WET AND DRY PONDS

Dry Ponds

Low Density - drain 25 acres of rural residential and low density residential development, (average imperviousness of 20 percent) 30,000 ft storage volume, no permanent pool.

High Density - drain 10 acres of townhouse/garden apartment, high-rise, and industrial/commercial development (average imperviousness of 50 percent), 33,000 ft storage volume, no permanent pool.

Wet Ponds

Low Density - drain 25 acres of rural and low density residential development (20 percent imperviousness), 75,000 ft volume with 45,000 ft of permanent storage. Normal detention times.

High Density - drain 50 acres of medium and high density development (50 percent average imperviousness), 250,000 ft volume, with 90,000 ft of permanent storage. Extended detention times of up to 30 hours.

In order to simulate this option within the context of the model, the runoff and sediment from new development were routed through storage basins before being delivered to stream channel. These empty basins were set up to duplicate the storage volume and release rate necessary to attenuate the 2-year peak flow in a conventional dry pond. To reflect a realistic degree of implementation in the basin, it was further assumed that the dry ponds would be applied to only 70 percent of new development included in the MNCPPC planning alternatives.

The principal characteristics and storage requirements of the simulated dry ponds are shown in Table 6.2. In general, the dry ponds provided only a minimal amount of sediment and nonpoint source control, principally because of their brief retention times. However, the flow attenuation may effectively act to reduce peak flows and streambank erosion.

Wet Stormwater Ponds

An urban nonpoint source management program involving full application of "wet" stormwater ponds was evaluated to examine the effectiveness of controls specifically designed to modify the quality as well as the quantity of urban runoff. In the modeling analysis, wet ponds were selected as the control to be applied to all new development since they have been demonstrated to achieve high levels of pollutant removal and stormwater attenuation, and represent a commonly used practice within the Metropolitan Washington Area. Long term removal efficiencies on the order of 40 and 70 percent for sediment, and 40 to 50 percent for total phosphorus, have been demonstrated in local test sites in the NURP study. These high efficiencies are accomplished principally through settling and biological filtering. The major characteristics and storage volumes of the simulated wet ponds is also provided in Table 6.2.

For low density development, (i.e., less than 10 dwelling units per acre) wet ponds were simulated with a permanent pool capable of attenuating peak discharge to two-year predevelopment levels. In the case of high density development, (i.e., more than 10 dwelling units per acre or commercial) extended detention wet ponds were applied to realize greater water quality improvements. Key features of these extended detention ponds applied to high density development were: a larger drainage area, extra volume for extended detention, and a drawdown time in excess of 30 hours. For both the regular and extended detention wet ponds it was assumed that the permanent pool contained a volume equivalent to one-half inch of runoff over the drainage area.

Agricultural Controls

The agricultural best management practice control program was drawn from the recently completed Soil Conservation Service (SCS) watershed management plan for Little Seneca. The plan incorporates land treatment and waste management practices intended to reduce erosion, sedimentation and water quality problems that originate from agricultural land. For cropland, the SCS plan specifies conservation cropping and tillage, contour farming, retention of crop residue and stubble, and the use of diversions and grassed waterways where needed. These practices would improve cover, increase infiltration, reduce sheet and rill erosion, and lessen the runoff, sediment, and nonpoint source loads generated from croplands. For livestock operations, the plan recommends the development of waste management collection systems and the development of springs for water supply and erosion control. The intent of these actions would be to minimize the delivery of waste and pollutants from heavily used livestock areas to streams, and to reduce erosion and bank trampling where feasible.

Mixed Urban and Agricultural Controls

The final control option that was assessed combined the agricultural practices and the urban nonpoint source management program as discussed above. The intent was to evaluate and contrast the individual control options with a scenario that represented a maximum application of urban and agricultural controls.

Incorporation of Controls into the Model

In the case of agricultural controls, the hydrologic consequences of the controls, i.e., greater infiltration, etc., were directly simulated, while the reductions in sediment and nonpoint source generation were adjusted based on average removal efficiencies described in the SCS Watershed Plan. For urban areas, the hydrologic response of the wet and dry ponds was also directly incorporated in the model. Through the use of storage basins average sediment and pollutant removal efficiencies derived from the observed long term behavior of existing ponds in the Washington area were applied. (MWCOG, 1983b) The results therefore reflect the average response to be expected from implementation of the controls. These estimates of pollutant removal efficiency are compared in Table 6.3.

Table 6.3

ASSUMED POLLUTANT REMOVAL EFFICIENCY
OF NONPOINT SOURCE CONTROLS

CONTROL STRATEGY	REMOVAL EFFICIENCY			
	NITROGEN	PHOSPHORUS	BOD	SEDIMENT
	PERCENT			
DRY STORMWATER POND	0	0	0	10-32
WET STORMWATER POND				
. REGULAR	30	50	50	42-62
. EXTENDED DETENTION	50	75	75	52-72
AGRICULTRUAL BMPs				
. PASTURE (acre)	18	14	38	5
. CROPLAND (acre)	27	36	29	36

Removal efficiencies for ponds based on preliminary long-term removal rates determined in NURP study. Agricultural BMP rates derived from Little Seneca Watershed Conservation Plan.

PROJECTED EFFECTIVENESS OF STORMWATER AND NONPOINT SOURCE CONTROLS

This section presents tabular and graphical summaries of the Clarksburg model projections for the 25 combinations of land use planning measures and basin wide control strategies. The water quality projections for the EXISTING and PRISTINE land use conditions have also been included as a reference.

Chlorophyll "a" Levels in Little Seneca Lake

Projected mean annual chlorophyll "a" levels within Seneca Creek under each of the land use planning/control strategies are depicted in Figure 6.1. As can be seen in the graph, the most effective control strategy is the utilization of wet ponds in concert with agricultural best management practices. Chlorophyll "a" levels (used as an indicator of algal concentration, and indirectly, as the degree of nutrient enrichment, or eutrophication) are reduced below 20 micrograms per liter in all of the land use plans analyzed. 20 micrograms per liter has been suggested to be a lower threshold for the onset of severe eutrophication in other local studies (NVPDC, 1982). Therefore, the mixed BMP control strategy has the potential to reduce the likelihood that Little Seneca Lake will experience severe eutrophication problems in the future.

As far as the other strategies are concerned, the implementation of a wet pond control program appears to be capable of reducing mean annual chlorophyll "a" concentrations by 5 to 14 micrograms per liter. An agricultural BMP program would be slightly less effective, with chlorophyll "a" reductions of approximately 2 to 7 micrograms per liter. In both cases, algal levels are projected to be lower than the existing condition, but still above the 20 microgram/liter threshold.

Land use planning measures have a variable impact on algal levels in the lake. Projected chlorophyll "a" levels range from a high of 31 micrograms per liter for the OPTION B and OPTION C land use plans to a low of 26 mcirograms under the ULTIMATE plan. However, algal levels throughout this range would be sufficient to induce severely eutrophic conditions.

Finally, the implementation of a dry stormwater pond program was projected to have little, if any, effect over the uncontrolled conditions.

Sediment Yield to Lake

Figure 6.2 presents the comparative effectiveness of the 25 land use planning/control strategies in reducing sediment loads to Little Seneca Lake. From the graph, it appears evident that the use of land use planning measures alone will not reduce sediment loads to the lake. Increases in sediment yield of 8 percent (ULTIMATE) to 30 percent (OPTION C) from existing conditions are predicted (see Table 6.5).

The implementation of agricultrual BMP's has a moderate potential for sediment reduction, in those land use alternatives in which agricultural land is retained in reasonable quantity. For example, agricultural BMP's applied to the OPTION A and OPTION B land use plans were projected to reduce overall sediment loads to the lake by 10 and 14 percent below existing levels, respectively.

Figure 6.1 Projected Effectiveness of Controls:
Chlorophyll "a" Levels in Lake

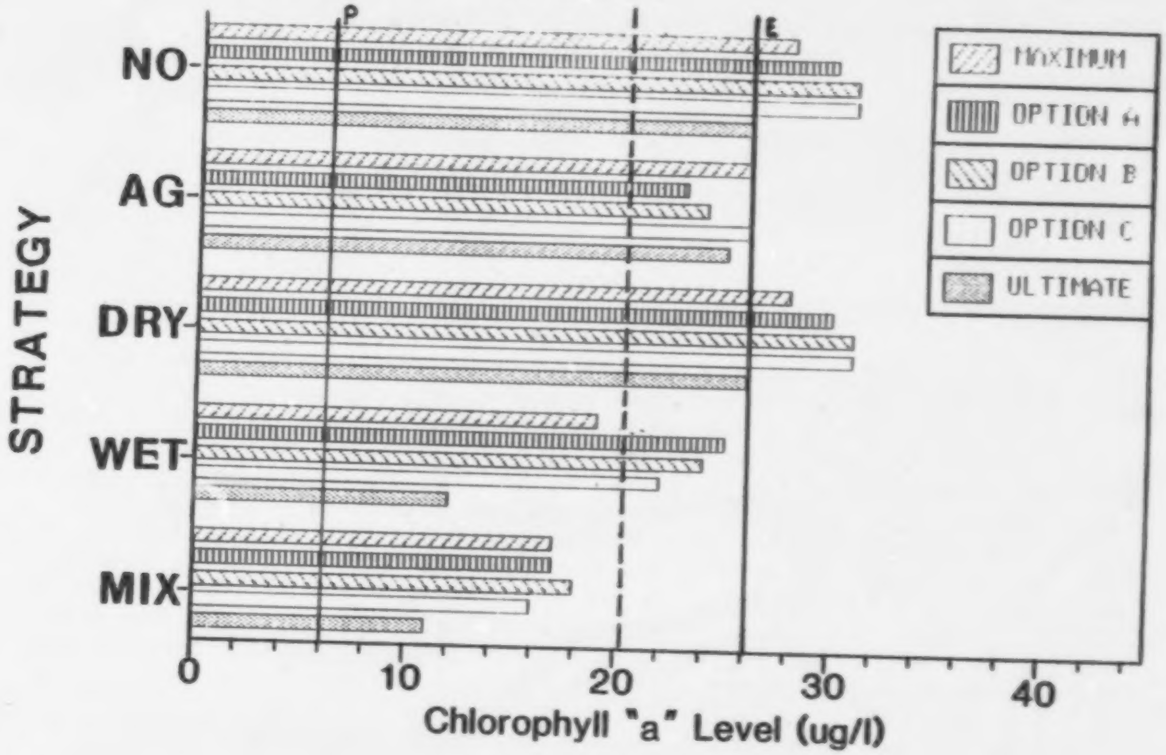


Figure 6.2 Projected Effectiveness of Controls:
Sediment Yield to Lake

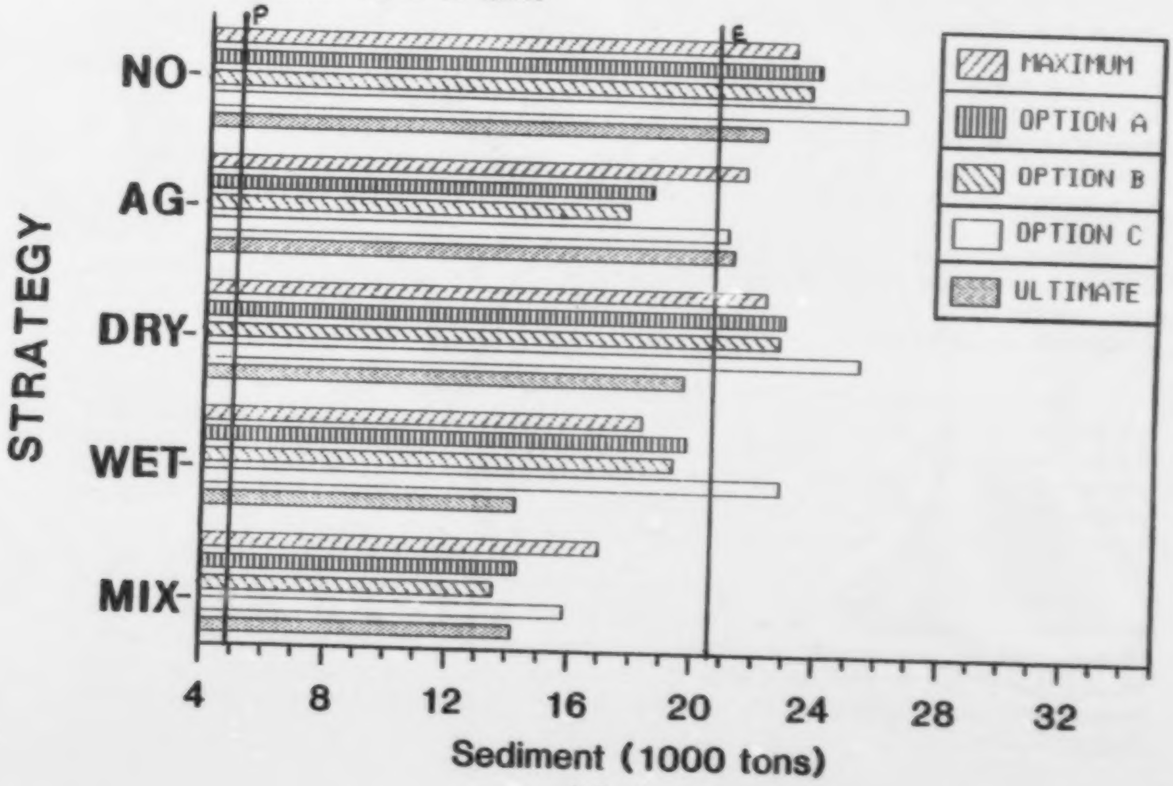


Table 6.4 Summary of Model Projections for Control Options in the Clarksburg Planning Area

PLANNING ALTERNATIVES CONTROL STRATEGY	IMPACTS TO TRIBUTARIES: HYDROLOGIC: PEAK DISCHARGE cfs	HYDROLOGIC: STORMWATER VOLUME cfsd	HYDROLOGIC: LOW FLOWS cfs	SEDIMENT RELATED: STREAMBANK EROSION tons/mi/yr	SEDIMENT RELATED: CHANNEL DEPOSITION tons/mi/yr	SEDIMENT RELATED: SUSPENDED EXCEEDANCE days>100mg/l	SEDIMENT RELATED: SEDIMENT FREQUENCY days>300mg/l	IMPACT TO LITTLE SENECA LAKE: WATER QUALITY LOADS: TOTAL PHOSPHORUS lbs	WATER QUALITY LOADS: TOTAL NITROGEN 1000 lbs	WATER QUALITY LOADS: BIOLOGICAL OXYGEN DEMAND 1000 lbs	SEDIMENT tons	IMPACTS: SEDIMENT DEPOSITION acre-feet	IMPACTS: CHLOROPHYLL "a" LEVEL ug/l
PRISTINE (REFORESTED)	1299	17.0	5.8	60	13	21	7	2,990	78	336	4,880	3.3	6
EXISTING (1980 LAND USE)	1400	20.1	5.5	115	122	40	23	14,500	221	810	20,500	15.7	20
MAXIMUM LAND USE PLAN	1885	26.2	5.0	210	114	48	29	15,820	262	1,098	23,100	17.7	28
AG CONTROLS	1870	"	5.1	200	106	47	29	15,030	258	971	21,950	16.0	26
DRY PONDS	1644	"	5.0	206	90	48	29	15,820	262	1,098	22,260	16.6	26
WET PONDS	1408	"	5.3	161	78	50	27	10,900	212	684	18,340	13.6	19
MIXED BMPs	1367	"	5.5	148	70	60	27	10,110	205	637	17,000	12.6	17
OPTION A PLAN	1775	24.8	4.9	189	124	45	27	17,130	281	1,069	23,900	17.8	30
AG CONTROLS	1751	"	5.1	182	85	44	28	13,090	265	860	18,530	13.0	23
DRY PONDS	1568	"	5.0	175	101	45	27	17,130	281	1,069	22,900	17.0	30
WET PONDS	1408	"	5.3	143	92	48	25	13,110	241	762	19,000	14.7	25
MIXED BMPs	1370	"	5.4	121	55	47	24	9,000	201	600	14,310	10.5	17
OPTION B PLAN	1562	24.2	5.0	160	126	45	27	17,350	287	1,044	23,600	17.5	31
AG CONTROLS	1529	"	5.1	146	92	43	25	13,680	242	832	17,730	13.2	24
DRY PONDS	1539	"	5.5	158	108	44	25	17,350	287	1,044	22,740	16.9	31
WET PONDS	1388	"	5.3	96	91	42	23	13,650	246	770	19,360	14.4	24
MIXED BMPs	1355	"	5.5	95	70	42	20	10,390	202	597	13,570	10.1	18
OPTION C PLAN	1865	26.5	4.6	243	115	51	31	17,630	311	1,186	26,700	19.8	31
AG CONTROLS	1800	"	4.8	224	84	50	28	14,660	256	922	21,000	14.9	26
DRY PONDS	1610	"	4.6	236	92	51	31	17,630	311	1,186	25,360	18.9	31
WET PONDS	1512	"	5.5	187	78	61	39	13,030	248	780	22,840	17.0	22
MIXED BMPs	1485	"	5.6	176	48	61	33	10,050	212	632	15,860	11.8	16
ULTIMATE PLAN	1947	27.8	4.4	248	83	51	31	14,600	243	1,083	22,130	16.5	26
AG CONTROLS	1944	"	4.4	231	80	50	29	14,200	243	1,050	21,200	15.8	25
DRY PONDS	1632	"	4.5	241	41	51	31	14,600	242	1,083	19,630	14.6	26
WET PONDS	1348	"	4.9	188	16	57	35	6,950	168	526	14,250	10.5	12
MIXED BMPs	1344	"	4.9	187	16	57	35	6,870	164	523	14,180	10.5	11

Table 6.5 Summary of Model Projections for Selected Control Options in the Clarksburg Planning Area - Net Change Relative to Existing Conditions

	IMPACTS TO TRIBUTARIES							IMPACT TO LITTLE SENECA LAKE					
	HYDROLOGIC			SEDIMENT RELATED				WATER QUALITY LOADS			IMPACTS		
PLANNING ALTERNATIVES CONTROL STRATEGY	PEAK DISCHARGE cfs	STORMWATER VOLUME cfsd	LOW FLOWS cfs	STREAMBANK EROSION tons/mi/yr	CHANNEL DEPOSITION tons/mi/yr	SUSPENDED EXCEEDANCE days 100mg/l	SEDIMENT FREQUENCY days>300mg/l	TOTAL PHOSPHORUS lbs	TOTAL NITROGEN 1000 lbs	BIOLOGICAL OXYGEN DEMAND 1000 lbs	SEDIMENT tons	SEDIMENT DEPOSITION acre-feet	CHLOROPHYLL "a" LEVEL ug/l
MAXIMUM LAND USE PLAN	+35	+30	-10	+90	- 7	+20	+26	+ [illegible]	+19	+36	+13	+13	+ 8
AG CONTROLS	+34	"	- 8	+74	-13	+18	+26	+ 7	+17	+20	+ 5	+ 5	0
DRY PONDS	+17	"	-10	+78	-26	+20	+26	+ 7	+19	+36	+ 9	+ 9	+ 8
WET PONDS	+ 1	"	- 4	+40	-36	+25	+17	-26	- 4	-18	-11	-11	-27
MIXED BMPs	- 2	"	0	+29	-57	+25	+17	-31	- 7	-21	-17	-17	-35
OPTION A PLAN	+27	+23	-12	+64	+ 2	+13	+17	+16	+27	+32	+17	+17	+15
AG CONTROLS	+25	"	- 8	+41	-30	+10	+13	- 6	+11	+ 7	-10	-10	-12
DRY PONDS	+11	"	-10	+50	-17	+13	+17	+16	+27	+32	+12	+12	+15
WET PONDS	0	"	- 4	+24	-25	+20	+ 9	-11	+ 9	- 6	- 4	- 4	- 4
MIXED BMPs	- 3	"	- 2	+ 5	-55	+18	+ 4	-33	- 9	-26	-31	-31	-35
OPTION B PLAN	+12	+20	-10	+40	+ 3	+13	+17	+18	+30	+29	+15	+15	+19
AG CONTROLS	+ 9	"	- 8	+27	-25	+ 8	+ 9	- 7	+10	- 3	-10	-10	- 8
DRY PONDS	+10	"	-10	+37	-11	+10	+13	-18	+30	+29	+11	+11	+19
WET PONDS	- 1	"	- 4	-17	-26	+ 5	0	- 7	+11	- 5	- 6	- 6	- 8
MIXED BMPs	- 3	"	0	-17	-57	+ 5	-13	-30	- 9	-26	-34	-34	-31
OPTION C PLAN	+33	+32	-20	+111	- 6	+28	+35	+20	+41	+46	+30	+30	+19
AG CONTROLS	+32	"	-15	+ 95	-31	+25	+35	- 1	+16	+14	+ 2	+ 2	0
DRY PONDS	+15	"	-20	+105	-25	+28	+35	+28	+41	+46	+24	+24	+13
WET PONDS	+ 8	"	0	+ 63	-36	+53	+70	-12	+12	- 4	+11	+11	-15
MIXED BMPs	+ 6	"	+ 2	+ 53	-61	+53	+70	-32	- 4	-22	-23	-23	-39
ULTIMATE PLAN	+39	+38	-25	+116	-32	+28	+35	- 1	+10	+34	+ 8	+ 8	0
AG CONTROLS	+39	"	-25	+101	-34	+25	+29	- 4	+10	+30	+ 3	+ 3	- 4
DRY PONDS	+17	"	-22	+110	-66	+26	+35	- 1	+10	+34	- 4	- 4	0
WET PONDS	- 4	"	-12	+ 63	-87	+43	+52	-53	+24	-35	-30	-30	-30
MIXED BMPs	- 4	"	-12	+ 63	-87	+43	+52	-53	-26	-35	-31	-31	-31

[a] Change relative to existing conditions.

By way of contrast, the dry pond program had only a marginal effect on sediment loads. In general, the sediment loading under a basin-wide dry pond program was projected to be from 10 to 25 percent greater than existing sediment loads.

The basin-wide implementation of wet ponds was found to have a significant effect on reducing sediment yields to the lake. Net decreases ranging from 10 to 30 percent, below existing loading rates were projected by the model.

The greatest net reduction (17 to 34 percent) in sediment loading rates to the lake was observed when full implementation of wet ponds was coupled with extensive application agricultural controls.

Total Nitrogen Load Delivered to Lake

Figure 6.3 illustrates the response of the total nitrogen load delivered to the lake to the various control strategies designed to reduce it. As can be seen, land use planning measures, in the absence of any controls, do not reduce total nitrogen loads. Indeed, the total nitrogen load actually increases by 10 to 40 percent. The greatest increase was noted for OPTION C, a land use plan which has sizeable quantities of agricultural land and highly impervious areas. The smallest increases was projected for the ULTIMATE plan (which has no appreciable agricultural loadings) and the OPTION A plan (which has smaller urban loadings). In all cases, much of the increase in total nitrogen load can be attributed to the conversion of land uses with low nutrient loadings (such as forest, idle or grassed areas) to more developed land uses with higher nutrient loadings.

Agricultural controls are moderately effective in decreasing the projected future nutrient loads, but are not capable of reducing them to existing levels. Most of the nitrogen which is controlled by the agricultural BMP's is in organic form, whereas many of the biologically available forms remain relatively uncontrolled.

Dry ponds capture and trap a negligible quantity of the incoming nitrogen load from developing areas, and as a result, have virtually no effect in the quantity of total nitrogen delivered to the lake. By way of contrast, the full implementation of a basin-wide wet pond program was projected to reduce total nitrogen loads to the lake. Biological, chemical and physical removal processes operating within the wet ponds were responsible for approximately a 20 to 30 percent reduction in basin-wide nitrogen loadings. In the MAXIMUM and ULTIMATE land use plans, the use of wet ponds could actually reduce nitrogen loadings below existing levels.

As would be expected, the implementation of both agricultural BMP's and wet ponds, can effectively control total nitrogen loadings. The reductions in nitrogen delivered to the lake ranged from 5 to 25 percent, relative to existing conditions.

Oxygen Demanding Materials Delivered to the Lake

Figure 6.4 illustrates the response of five day BOD loads to the five control strategies. The pattern of projected effectiveness which was observed was quite similar to that seen for chlorophyll "a", sediment and nitrogen.

Figure 6.3 Projected Effectiveness of Controls:
Nitrogen Inputs to Lake

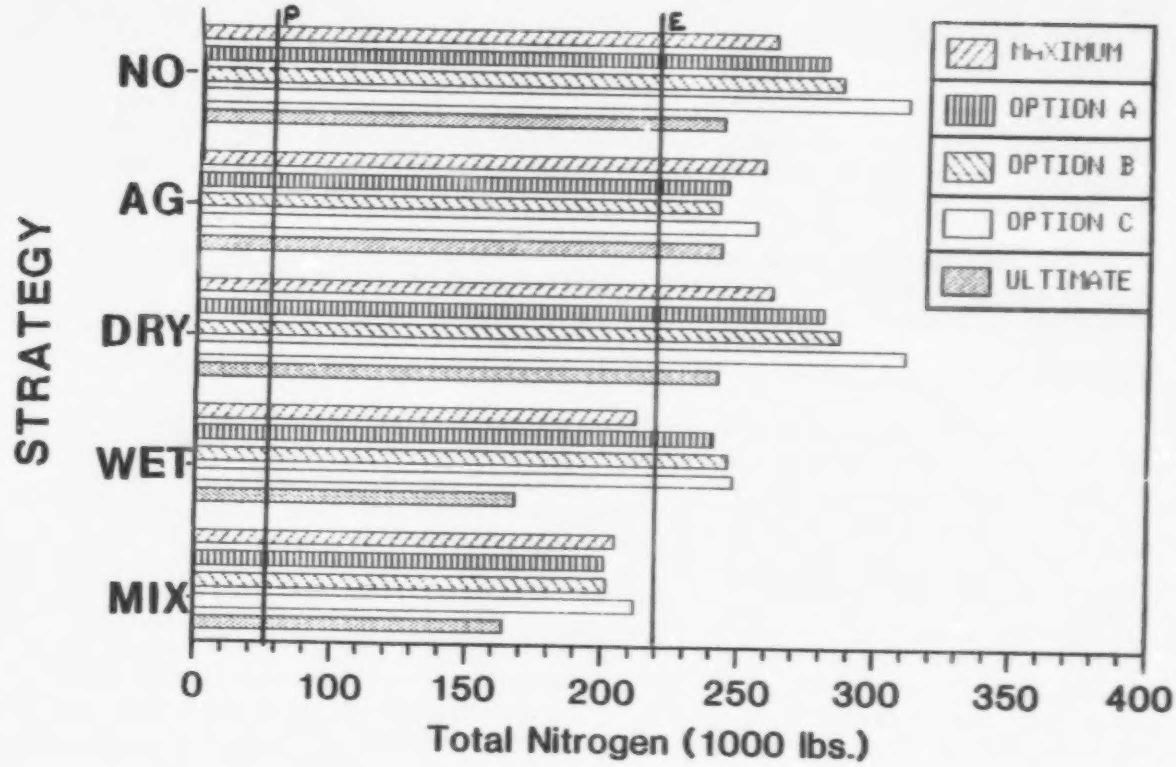
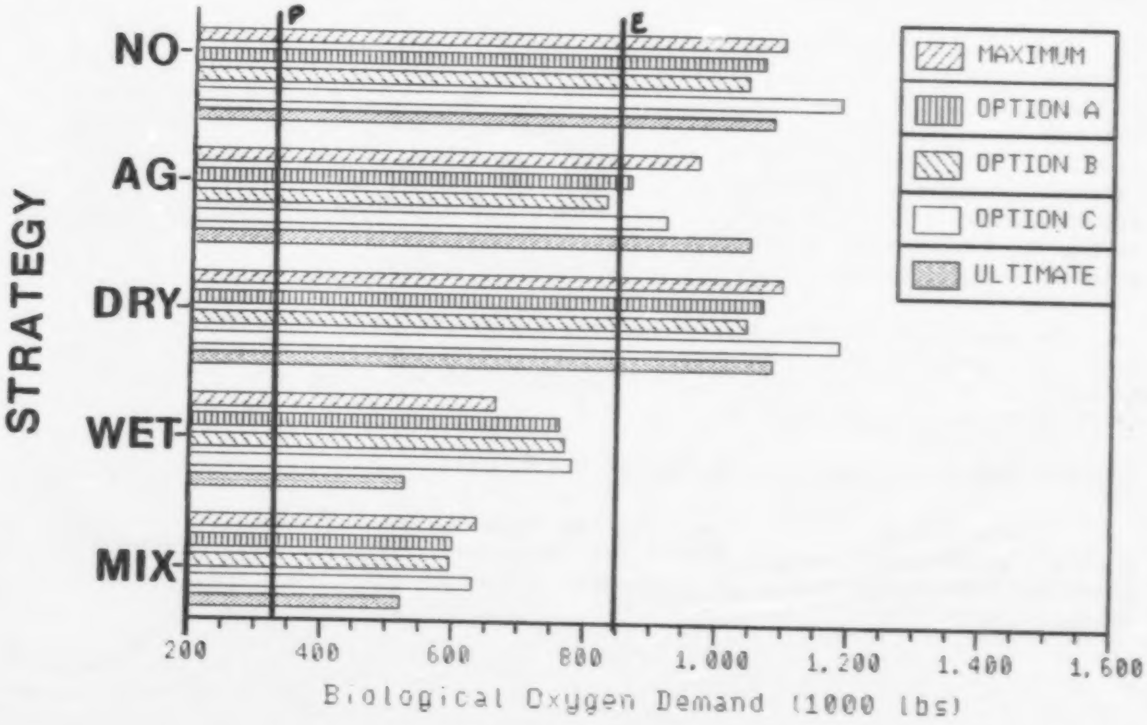


Figure 6.4 Projected Effectiveness of Controls:
Oxygen Demanding Materials



Land use planning measures had the net effect of increasing BOD loads by 29 percent to 46 percent. The greatest increase was recorded for the OPTION C plan, while the smallest increase was reported for the OPTION B plan. The general trend appeared to be that greater levels of development led to higher BOD loads.

Application of dry stormwater ponds to 70 percent of all new development had little effect on reducing the projected increases in BOD loads associated with future development. The ponds detained, but did not trap, oxygen demanding materials as they passed through the facility.

Implementation of best management practices on agricultural lands had a substantial effect in limiting the BOD loads to the lake. These practices, which involved improved management of livestock wastes, were projected to result in total BOD loads which were about the same level as existing loading rates. As with most of the other model projections, the greatest effect of agricultural BMP's was observed in the land use plans which retained croplands in appreciable quantities.

When wet ponds were applied to 100 percent of all new development, considerable improvement in BOD loadings to the lake were realized. The reductions, relative to existing conditions, ranged from 3 percent (OPTION B) to 35 percent (ULTIMATE).

Finally, when the wet pond control program was coupled with the agricultural controls, BOD loads declined by 20 to 35 percent in all of the land use plans.

Peak Discharge in Tributary Streams

One of the major concerns of any watershed management program is the effect of land use changes on peak flow, or flooding potential of streams. Besides the obvious adverse consequences to human life and property, increases in stormwater flows can have pervasive impacts on the quality of aquatic and riparian habitat in streams. Some of these habitat impacts include channel widening, changes in bed composition, and stream bank erosion.

Figure 6.5 illustrates the watershed response to the largest storm event during the year of simulation, for each of the 25 land use control strategy combinations. (It should be noted that this storm event was somewhat smaller than the two year design storm. Detailed evaluations of the impacts of the two year design storm have been conducted in the Phase II study recently completed by CH2MHILL, (1983).)

As can be seen in the Figure, the land use planning measures under consideration by MNCPPC are projected to significantly increase peak flows within the watershed by 12 to 40 percent. OPTION B, which has the least basin imperviousness, was projected to have the lowest future increase in peak flows, whereas the more intensively developed options, MAXIMUM and ULTIMATE, were projected to have the highest peak flows.

As would be expected, the full implementation of agricultural controls was projected to have only a marginal effect on future peak discharges. The small reductions which were observed are attributed to enhanced infiltration of rainfall due to conservation tillage and cropping practices.

Figure 6.5 Projected Effectiveness of Controls:
Peak Discharge

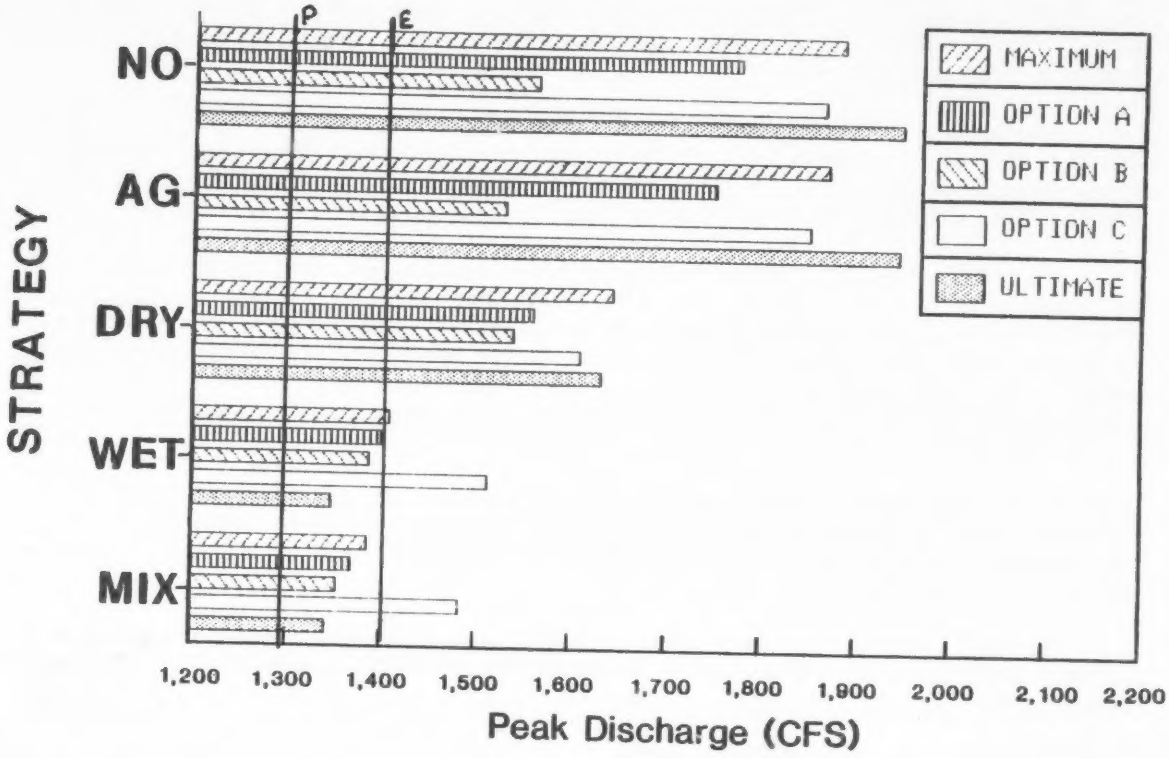
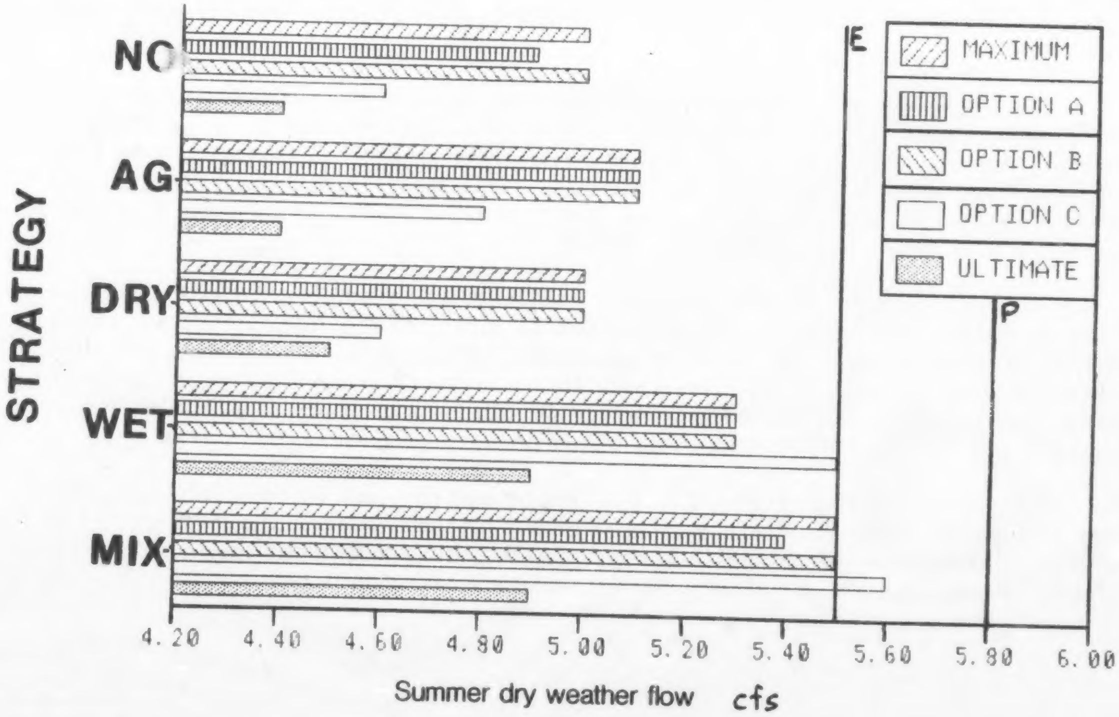


Figure 6.6 Projected Effectiveness of Controls:
Dry Weather Low Flows



The application of dry stormwater ponds to 70 percent of all new development was projected to be capable of significantly controlling future stormwater peak flows. However, future peak flows were projected to still be 9 to 17 percent higher than those experienced under existing conditions.

A wet stormwater pond control program exhibited even greater control over peak stormwater flows. With the exception of the OPTION C land use plan, all of the wet pond control strategies were capable of controlling peak discharge to levels below existing conditions. This result is especially interesting since all of the storage basins representing wet ponds within the model discharged simultaneously. (Some authors have suggested that downstream stormwater flows would not be altered under this condition.) Much of the reduction in peak flow under the wet pond control strategy can be attributed to extended detention.

Finally, when wet ponds were applied in concert with agricultural controls, there were no significant decreases in peak stormwater flows beyond those noted for wet ponds alone.

Dry Weather Low Flow in Tributary Streams

A commonly cited impacted of increased urbanization on stream hydrology has been reduced dry weather flows. It is believed that since most of the incoming rainfall quickly runs off, much of the recharge of shallow groundwater will be diminished. As a consequence, the ability of an urban stream to sustain normal flows during dry weather periods would be curtailed. Figure 6.6 depicts the watershed response to the 25 land use option/control strategy combinations, in terms of dry weather low flows.

While all of the land use planning measures under consideration by MNCPPC exhibit some reductions in dry weather flow, there is considerable variation in the severity of the reduction. In the intensively developed OPTION C and ULTIMATE land use plans dry weather low flows are diminished by 20 and 25 percent, respectively, while in the OPTION B plan, flows are only reduced by 10 percent.

Agricultural BMP's and dry stormwater ponds were projected to have a relatively small effect on dry weather low flows. On the other hand, the full implementation of wet stormwater ponds to 100 percent of all new development was projected to sustain dry weather flows within 4 to 12 percent of existing levels. The wet ponds served to elevate dry weather low flows by gradually releasing water during extended periods of no precipitation. Other urban BMP's which utilize infiltration techniques such as porous pavement are presumed to have even a greater effect on sustaining dry weather low flows.

Streambank Erosion

Figure 6.7 depicts the response of streambank erosion rates to differing land use planning measures and control strategies. A quick glance at the graph suggests that the streambank erosion rate is extremely sensitive to the prevailing land use pattern. While all future land use plans entail some increase in the streambank erosion rate, the degree of increase varies substantially among land use planning alternatives. For example, the streambank erosion rate climbs by over 110 percent in the most developed plans, (OPTION C and ULTIMATE), but only 40 to 65 percent in the least developed plans (OPTION B and OPTION A, respectively).

Figure 6.7 Projected Effectiveness of Controls: Streambank Erosion Rates

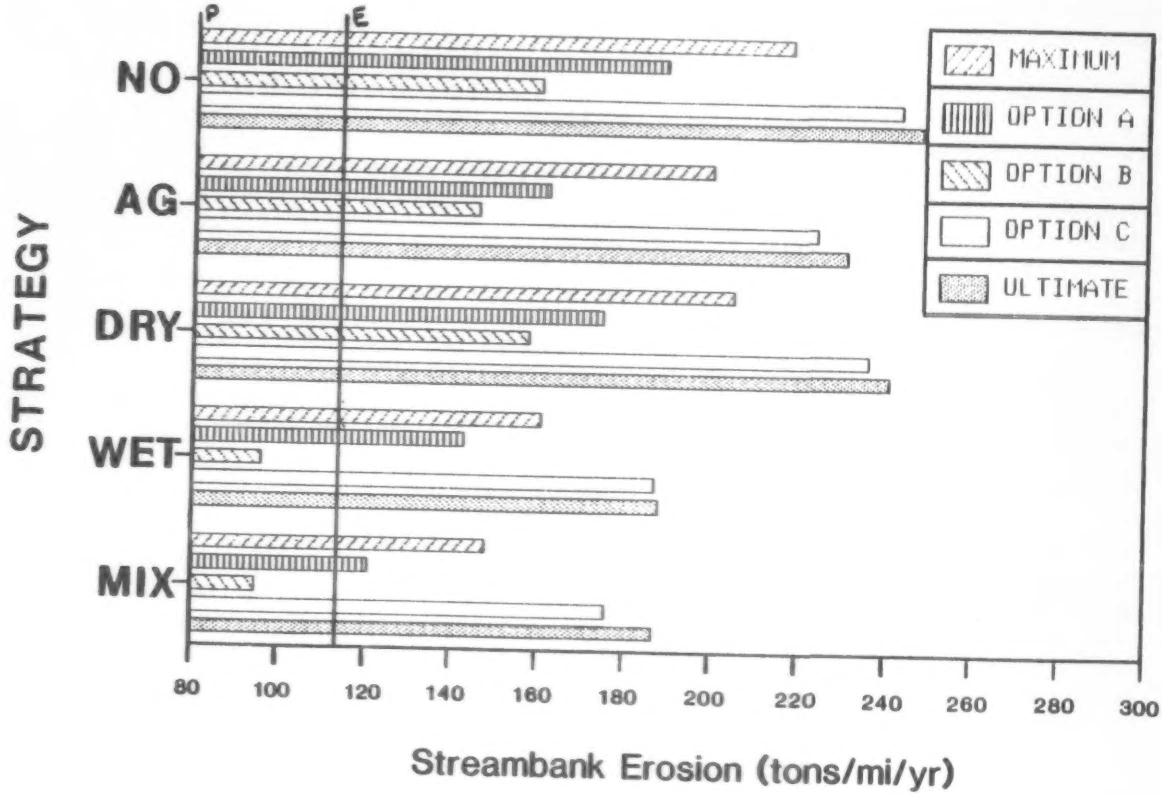
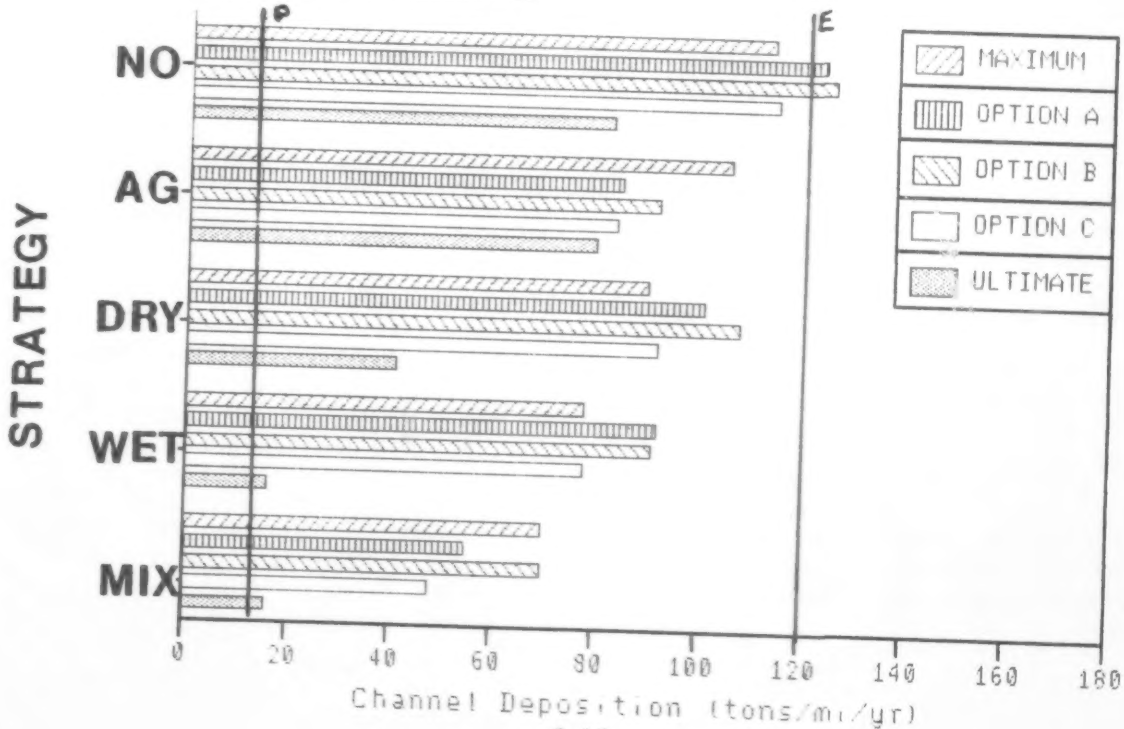


Figure 6.8 Projected Effectiveness of Controls: Deposition of Sediments



A second conclusion that can be drawn from Figure 6.7 is that while the various control strategies all can mitigate streambank erosion to a degree, none of them were capable of reducing rates to levels approaching those observed under existing conditions. Application of agricultural BMP's, for example, were projected to reduce streambank erosion rates by 15 to 20 tons per stream mile. (These BMP's involved measures which prevented livestock from trampling the banks of streams running through pastured areas.) Reductions of 5 to 15 tons per stream mile were projected for dry ponds as well. The rather low effectiveness of dry ponds in mitigating streambank erosion appears surprising. However, model sensitivity runs provide evidence that the rate of streambank erosion appears to be primarily determined by the duration of stormwater flows above a certain threshold, rather than the height of the peak flow event. Also, there has been some research which indicates that the total downstream flow reduction from a basin-wide network of dry stormwater ponds may be less than the sum of their individual effects on flow, because of discharge-timing problems inherent in siting (Traver and Chadderton, 1983).

Wet ponds were projected to have greater effect on mitigating streambank erosion. Reductions on the order of 45 to 60 tons per stream mile were typically exhibited in the model simulations. Wet ponds did appear to be affected by some of the same discharge-timing problems noted in the dry pond scenario, and the additional reductions in streambank rates were probably attributable to the more gradual release of the high density extended detention wet ponds.

The implementation of wet ponds and agricultural BMP's together was projected to reduce streambank erosion rates by 60 to 70 tons per stream mile.

Deposition of Sediments in Tributary Streams

Not all of the sediment which enters a stream is eventually delivered to receiving waters. The heavier and coarser fractions of the sediment load usually falls out of suspension and enters channel storage. The resulting sediment deposition can smother benthic communities. Figure 6.8 details the projected changes in sediment channel deposition rates as a function of land use and control effectiveness.

The land use planning measures were projected to have a mixed effect on channel deposition rates, ranging from +3 percent (OPTION B) to -32 percent (ULTIMATE), relative to existing conditions. The explanation for this phenomenon is that agricultural sediments are normally more coarser-grained than those emanating from urban areas. As a result, the sediment eroded from agricultural areas is much less likely to be transported all the way to the lake in suspension, whereas the finer grained sediments washed off from urban areas have a greater probability of complete transport.

As can be seen in the figure, all of the control measures analyzed have a strong influence on reducing channel deposition rates. This is chiefly due to the fact that coarser grained sediment particles are usually the first ones to be trapped in a pond structure or retained on cropland by BMPs.

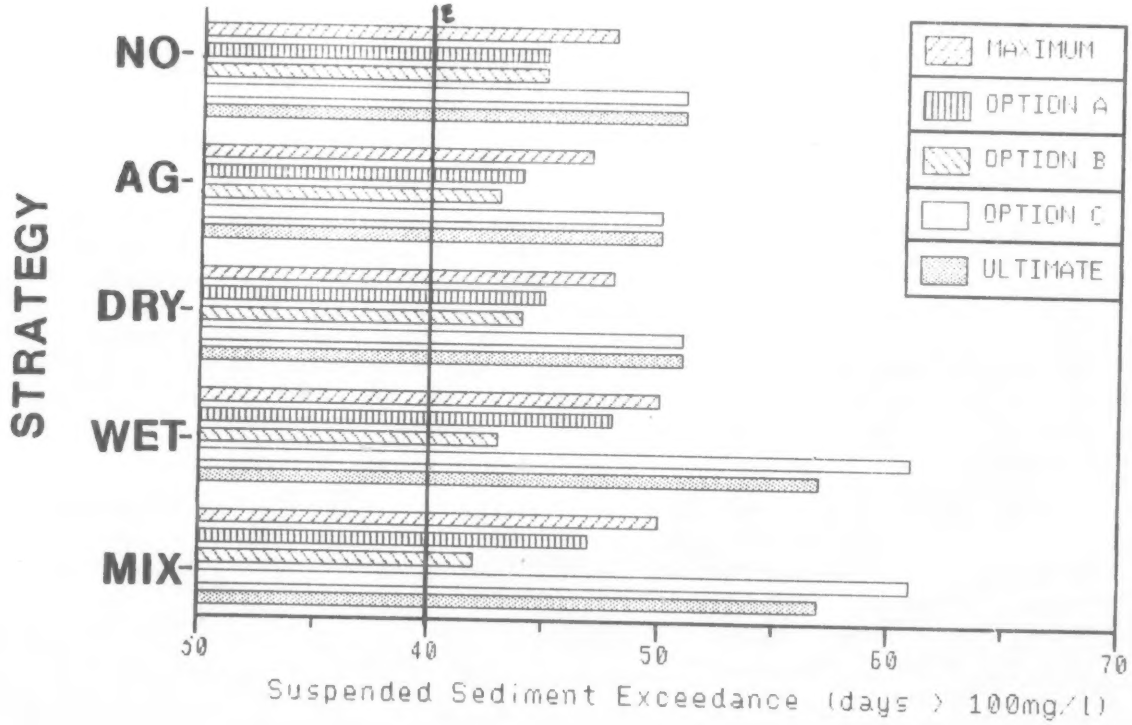
Suspended Sediment Concentrations

One of the unique capabilities of the HSPF model is the ability to calculate exceedance frequencies for specified threshold concentrations. This software was applied to estimate the number of days in which suspended sediment concentrations exceeded the threshold of 100 mg/l and 300 mg/l. The former threshold has been suggested as a criteria level for protection of aquatic life (AFS, 1980). Figure 6.9 illustrates the exceedance frequency for suspended sediment at 100 mg/l concentrations.

As indicated on the Figure, the future levels of development embodied in the land use planning measures were projected to increase the duration of suspended sediment concentration by 13 to 28 percent (approximately 5 to 11 days) relative to existing conditions. In general, the more intensively developed land use plans yielded the greatest exceedance frequencies.

None of the control measures had a positive effect on reducing the duration of suspended sediment frequencies. In fact, in some of the stormwater pond projections, the control measures actually increased the durations of high suspended sediment concentrations. This phenomenon can probably be explained by the fact that the ponds act to extend the duration of storm events, and consequently, the duration of high suspended sediment levels. Most of the control measures were reasonably effective in reducing the duration of suspended sediment levels at higher concentrations.

Figure 6.9 Projected Effectiveness of Controls: Suspended Sediment Levels



RELATIVE WATER QUALITY INDEX

A quick glance at the graphical and tabular summaries of the effectiveness of individual mitigation strategies reveals a bewildering pattern of complexity. For example, a given strategy might be extremely effective in reducing non-point loads to the lake, but may only have moderate effect on stream habitat conditions, and none whatsoever on hydrological regimes. On the other hand, another strategy may exhibit a completely different pattern of effectiveness. Therefore, efforts were made to condense the complete set of projections of each mitigation strategy into a format more meaningful to planners and decision-makers.

The chief purpose of this analysis was to arrive at an overall evaluation of each strategy, so that a determination could be made as to whether or not the implementation of that strategy would result in the maintenance or improvement of existing water quality conditions. As such, it was hoped that the index could serve as a broad screening tool with which to identify the most efficient mitigation strategies available.

To this end, a simple, unweighted index was developed. This index was based on the percent change, relative to existing conditions, for each of ten important water quality indicators. The scale of the index goes from -5 to +5, where zero represents no change from existing conditions, a negative score indicates impairment, and a positive score represents water quality improvement. Each unit on the scale represents a 25 percent increment of change, relative to existing conditions. The general features of the index, as well as the water quality indicators upon which it is based, are described in Table 6.6.

Application of the Overall Water Quality Index

The results of the indexing analysis are presented in graphical form in Figure 6.10 In the graph, each of the 25 control strategies are ranked in descending order, on the basis of their relative score in the water quality index. Both pristine and existing conditions have also been included to serve as a reference.

Several very interesting conclusions can be drawn about the comparative performance of control strategies. First, 14 out of the 25 control strategies result in projected overall water quality conditions which are worse than the existing condition. As a rule, these strategies either involve the use of dry stormwater ponds, and agricultural controls, or rely on land use planning measures alone.

By way of contrast, 11 of the strategies were projected to either maintain, or improve on existing water quality conditions. The common features of these control strategies is the employment of wet ponds alone, or in combination with agricultural controls.

Application of Sub-Indices

Four smaller versions of the overall water quality index were computed to obtain a precise indication of how a particular strategy performed with respect to certain specific impact categories. These impact categories were covered in the following sub-indices:

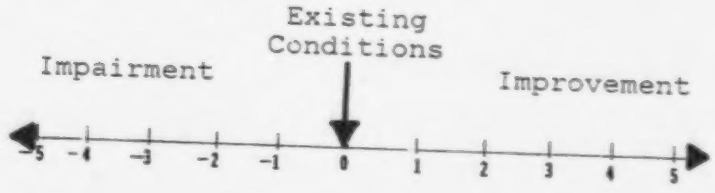
Stream Hydrology: Sum of percent change over existing conditions in peak discharge and low flows.

Sediment Related Impacts: Sum of percent change over existing conditions for streambank erosion, channel deposition, and suspended sediment concentration.

Nonpoint Source Loads: Sum of percent change over existing conditions, for total N, total P and BOD5 cumulative loads.

Relative Water Quality Index

- Used to condense model outputs for each land use planning/control strategy
- Provides a broad screening comparison of alternatives
- Based on percent change from existing conditions (+ or −) for ten water quality parameters
- Scale of index ranges from plus 5 to minus 5
- Each unit on scale represents a 25% increment of change, relative to existing conditions

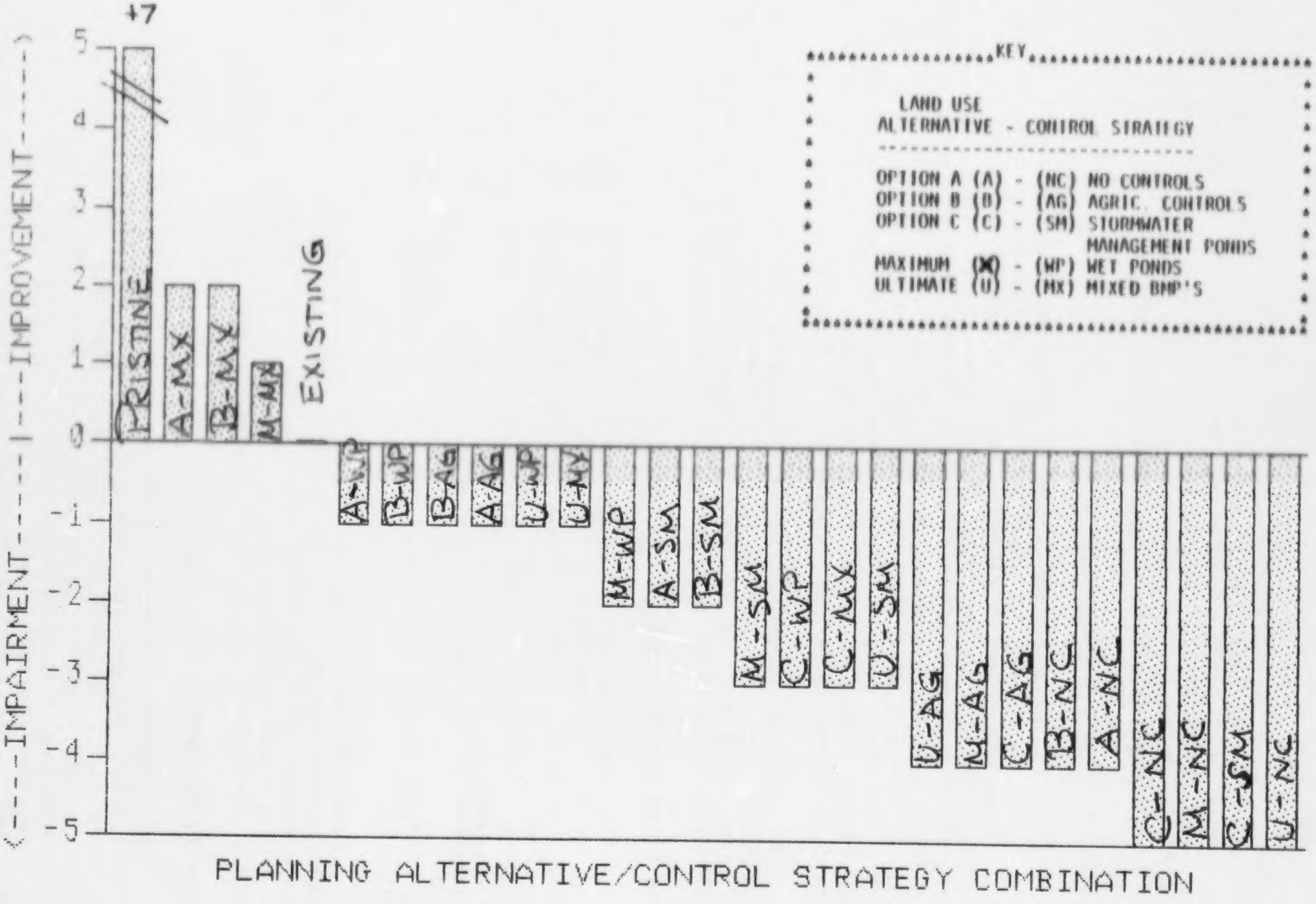


Parameters Evaluated By Index

Impacts To Tributaries:
- Peak discharge
- Summer dry weather flow
- Streambank erosion
- Channel deposition
- Suspended sediment exceedance frequency (days > 100 mg/l)

Impacts To Lake:
- Total nitrogen load
- Total phosphorus load
- Total BOD-5 load
- Estimated chlorophyll "a"
- Volume of sediment delivered to lake

Figure 6.10
Overall Water Quality Index



*Changes in Streambank Erosion, Channel Deposition, & Susp. Sediment Exceedance, relative to Existing Conditions.

Lake Water Quality: Sum of percent change in estimated chlorophyll "a" and volume of sediments delivered to lake.

Stream Hydrology Sub-Index

The results of the stream hydrology indexing (Figure 6.11) suggest that the hydrological impacts of increased development are not easy to mitigate. Out of the 25 strategies analyzed, only 5 were projected to improve stream hydrology conditions, relative to the existing condition. These strategies all involved the use of wet ponds or a mixed BMP strategy, in conjunction with land use planning measures that emphasized lower density land use. Of the 20 strategies which resulted in impaired hydrological conditions, the least effective strategies tended to rely on either land use planning measures alone, or agricultural controls.

Sediment Related Impacts Sub-Index

The results achieved in the sediment indexing analysis (Figure 6.12) are strikingly similar to those reported for the water quantity sub-index. Only three strategies were projected to cause an improvement in sediment related conditions in the tributary streams. All of these strategies employed a combination of agricultural and urban BMP's, and also were associated with the least intensive land use planning measures. Several other strategies, such as the use of wet ponds and higher density land uses or agricultural BMP's and lower density land use, were projected to bring about only modest impairment, relative to existing conditions. These strategies typically produced increases in index values of 3 to 4 units.

A definite trend towards increased sediment related impairment associated with the more intense land use plans is evident in Figure 6.12. As can be seen, 12 of the 16 "worst" strategies involved either the MAXIMUM, OPTION C, or ULTIMATE land use planning alternatives.

Non Point Source Loading Sub-Index

The projected index values for the nonpoint loading sub-index suggest that there is a remarkable potential for removal of watershed nutrient and BOD loadings. (Figure 6.13) Of the 25 control strategies analyzed, 11 resulted in net improvements in the nonpoint loading category, relative to existing conditions. Many of these successful strategies had net decreases in overall loads on the order of 50 to 75 percent. In general, these strategies all involved the use of wet ponds or mixed agricultural and urban BMP's. One strategy, calling for agricultural controls coupled with agricultural preservation also resulted in significant reductions in nonpoint loads.

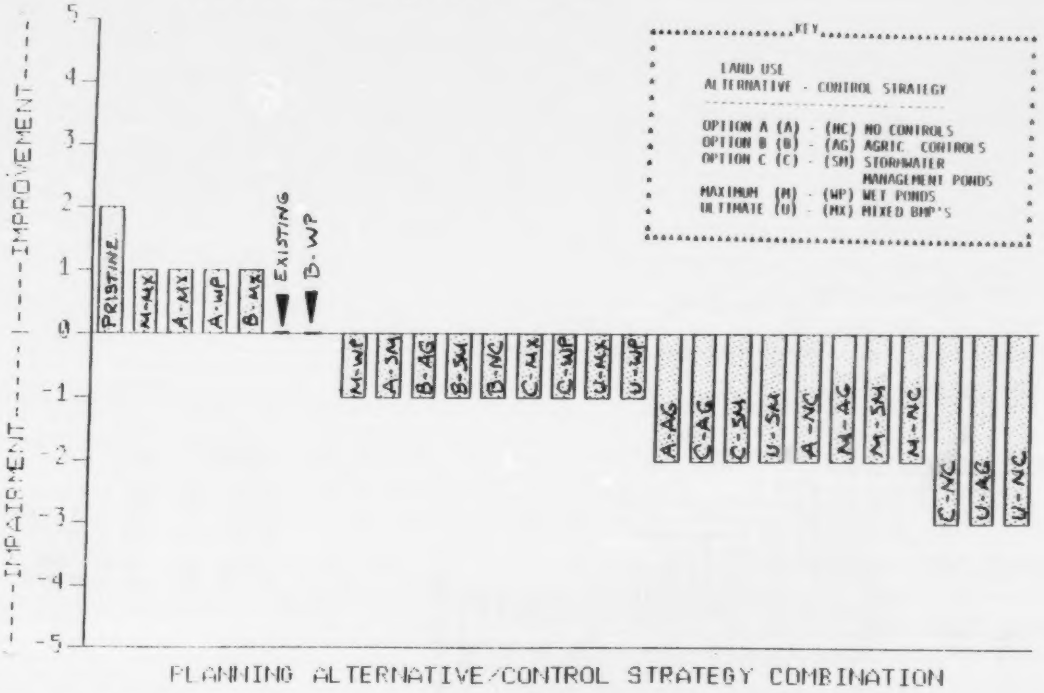
One interesting feature of this sub-index is the finding that the application of wet ponds to the highest density land use alternatives achieves the greatest net reduction in overall nonpoint loadings. This stems from the fact that these strategies have: 1) the least agricultural nonpoint loadings and 2) the highest percentage of watershed area under control.

Lake Water Quality Sub-Index

The results of the lake water quality indexing analysis are presented in Figure 6.14. In general, the projections of future lake water quality were quite encouraging, with 14 control strategies (out of a possible 25) achieving index values superior to existing conditions. As with other indexes, the most effective control strategies for protecting lake water quality typically involved the use wet ponds, or mixed BMP's. Some of the control which employed extensive application of agricultural controls in conjunction with lower density land use planning alternates, also achieved modest improvement in lake water quality. However, it should be noted that the existing

Figure 6.11

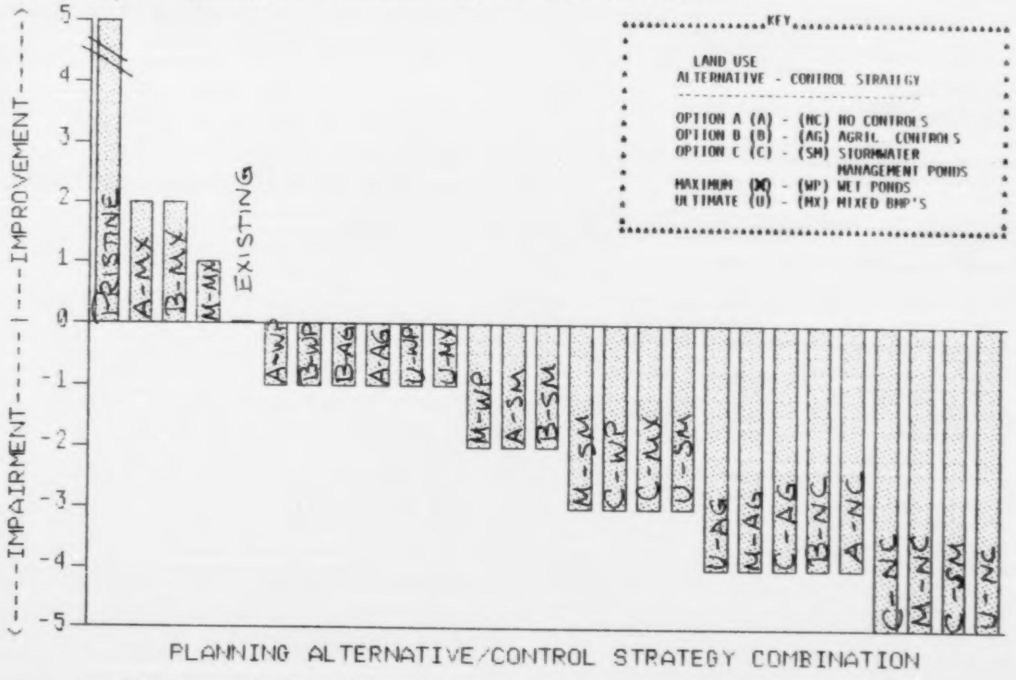
Stream Hydrology Sub-Index



*Changes in Peak Discharge & Summer Low Flow, Relative to Existing Conditions.

Figure 6.12

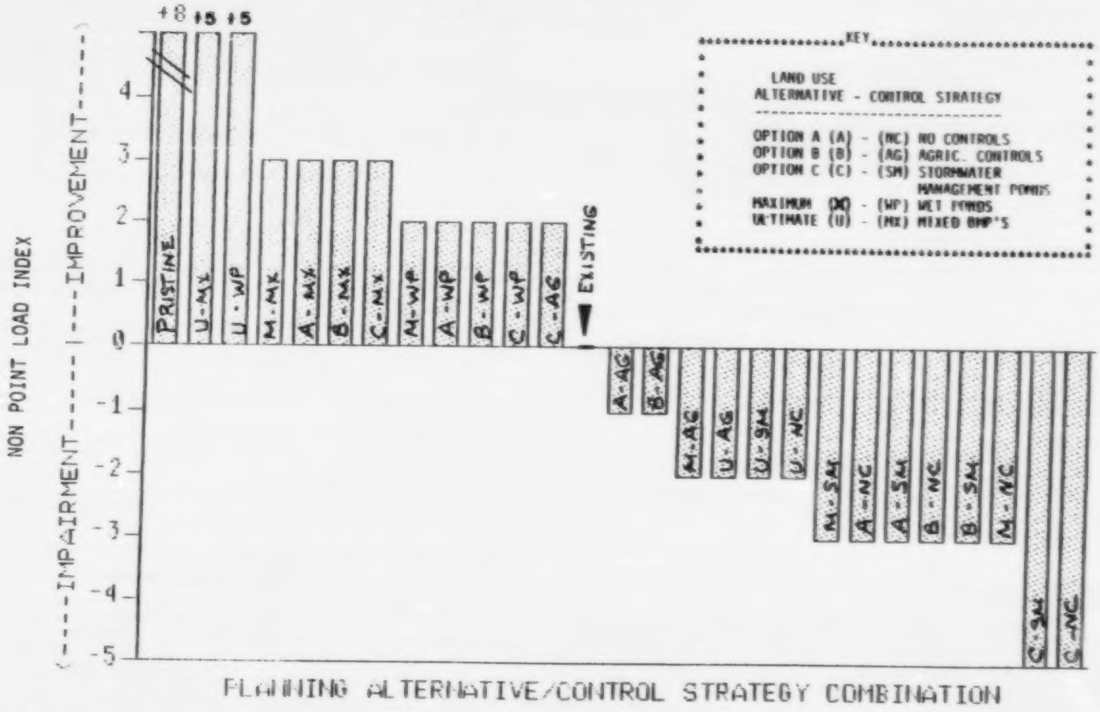
Sediment Related Impacts Sub-Index



*Changes in Streambank Erosion, Channel Deposition, & Susp. Sediment Exceedance, relative to Existing Conditions.

Figure 6.13

Nonpoint Source Loads Sub-Index

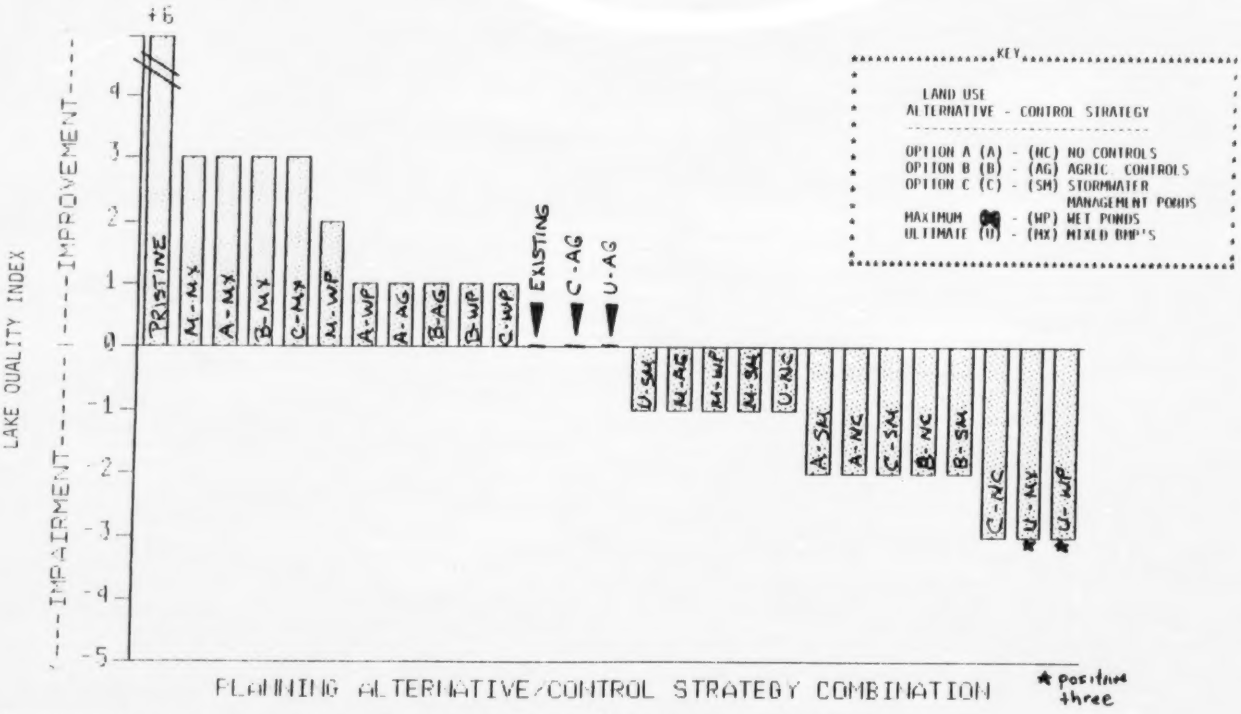


*Changes in TP, TN & Biological Oxygen Demand,
Relative to Existing Conditions.

situation may not be the best benchmark with which to evaluate lake water quality, since the existing land use pattern was projected to induce a highly eutrophic condition as well as generating a substantial sediment yield. Viewed in this light, only 7 of the 25 control strategies were projected to produce algal levels which were not highly eutrophic. The most effective control strategies in this regard were those that had the greatest watershed application of wet ponds and agricultural controls. A similar pattern was noted for sediment yield.

Figure 6.14

Lake Water Quality Sub-Index



Changes in Sediment Load & Chlorophyll "a" Level,
Relative to Existing Conditions.

SUMMARY: COMPARATIVE EFFECTIVENESS OF NONPOINT CONTROL STRATEGIES

Land Use Planning

Master plan alternatives calling for more intense development typically had the most severe impacts on stream habitat. These impacts included: increased peak discharge, diminished dry weather flows, higher streambank erosion rates and longer durations of high turbidity. On the other hand, the master plan alternatives which emphasized conservation of agricultural and forest lands, and were oriented towards lower density development, experienced less adverse impacts on stream habitat.

However, the planning alternatives which emphasized conservation of agricultural lands were projected to deliver nutrients and sediments to the lake in quantities which approached, and in some cases exceeded, those delivered in the more intensive development scenarios. This was largely due to the fact that agricultural loadings were normally higher than those from suburban areas. This suggests the need to couple agricultural preservation efforts with control of their nonpoint source loadings.

In terms of the water quality indices, all of the master planning alternatives had negative scores, which indicates future deterioration of stream habitat and lake water quality would be likely in the absence of any controls. However, the extent of the deterioration varied widely among the planning alternatives, with the less intensive land use plans having higher overall index scores than the more intensive ones.

Dry Stormwater Ponds

The application of "dry" stormwater ponds would not prevent much of the projected deterioration of water quality and stream habitat associated with future development in the Clarksburg Planning Area. The principal purpose of these structures, flood control, would be effectively served. (i.e., peak discharges would be shaved considerably through much of the watershed.) However, under existing dry pond design criteria only minimal reductions in sediment and nutrient loads would be achieved. Also, streambank erosion rates would only be marginally reduced. Similarly, no changes in dry weather low flow or duration of high stream turbidity levels were projected to occur. Finally, nutrient enrichment problems in the lake would not be noticeably diminished.

The results of the indexing analysis underscored the marginal value of a basin-wide dry pond control program. Negative index values were recorded in all of the indices computed, with the lowest values being reported for the non-point source load and sediment-related impacts sub-indices.

Agricultural Controls

Model projections indicated that agricultural BMP controls were a very effective strategy in the land use scenarios where agricultural lands were retained in sizeable quantities. Most of the water quality benefits were associated with reductions in watershed nutrient, sediment and BOD loads, resulting in corresponding declines in algal and turbidity levels in the Lake.

While the overall water quality index scores for the agricultural BMP control program indicated that future water quality conditions would be

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impaired relative to existing conditions, the degree of this impairment was usually not great.

Wet Stormwater Ponds

This control strategy was projected to be very effective in mitigating many of the adverse effects of future development. Peak discharges were reduced to pre-development levels (i.e., existing conditions) and dry weather low flows were moderately augmented. Uncontrolled streambank erosion rates were reduced by 25 to 40 percent. Similar or greater reductions were projected for basin wide nitrogen, phosphorus, and BOD loads delivered to the lake. Sediment loads were reduced by 15 to 35 percent. Projected algal levels in the Lake declined by 5 to 14 micrograms/liter of chlorophyll "a", suggesting a significant potential for alleviating the potential eutrophication problem in the Lake.

The wet pond control strategies consistently received positive scores within the context of the water quality indexing analysis. This suggests that future water quality conditions could be improved, relative to existing conditions, if a comprehensive wet pond program is implemented. The greatest improvements were recorded for the nonpoint source loads, lake water quality, and sediment-related impact sub-indexes.

Mixed Wet Pond and Agricultural BMP Strategy

The greatest degree of protection of lake water quality and stream habitat was realized when both urban and agricultural BMP's were implemented together. In all but the most developed scenario, combined application of both controls resulted in both enhanced water quality conditions in the lake, and significant reductions in the deterioration of stream habitat, relative to existing conditions. Specifically, projected chlorophyll "a" concentrations within the lake were typically reduced by 40 to 60 percent. Chlorophyll "a" reductions of this magnitude could prevent development of eutrophic conditions within the Lake. Sediment, nitrogen, phosphorus and BOD loadings were reduced to levels below those likely to be experienced under current land use patterns. Also, the flow regimes of the tributary streams (peak discharges and low flows) were not projected to change much from existing conditions. Streambank erosion rates in most scenarios were moderately reduced (25 to 45 percent.)

The mixed BMP program resulted in the highest overall scores in the water quality indexing analysis. Full implementation of this control program was projected to improve overall water quality conditions in all of the master planning alternatives studied. The largest improvement was recorded for the nonpoint source loads and lake water quality sub-indices. Also, the scores for the stream hydrology and sediment-related impact sub-indices indicated that these impacts could at least be reduced to levels similar to those experienced under existing conditions.

Chapter Seven

COST EFFECTIVENESS OF CONTROL STRATEGIES

ANALYSIS OF CONTROL COSTS

The full cost of implementing and operating a control strategy is often a major factor to be weighed in the development of an effective nonpoint source strategy. Such cost information, especially when combined with projections of relative effects on water quality can enable planners to gauge how much "bang" they get for their "buck".

To this end, particular emphasis was placed on projecting the total costs associated with each of the various nonpoint control strategies analyzed in the study. Total costs are defined here as the initial capital cost (including planning, design, construction and administration) and the subsequent cost of operating and maintaining a control for the duration of its useful life. All cost estimates were prepared assuming a twenty year project life, an eight percent discount rate, and a common price base (1980 dollars).

The major thrust of the analysis was a comparison of each land use planning/control strategy combination on the basis of both total cost and relative effectiveness.

This Chapter is organized in the following manner. First, the methodology and assumptions employed in deriving cost estimates for control is briefly is described. Secondly, results of the costing analysis are compared in terms of the differences in basin-wide and unit costs among different control alternatives. In the third section, the effectiveness of each control (as determined by its relative ranking in the water quality index - Chapter 6) is directly compared to its total cost. Finally, the implications of the cost/effectiveness analysis for developing and effective NPS strategy are discussed, and some of the potential benefits of a control program are explored.

Table 7.1

Estimated Total Costs for Unit Stormwater Ponds

POND TYPE	AVERAGE IMPERVIOUSNESS (%)	DRAINAGE AREA (Acres)	Volume OF STORAGE (cubic feet) (V_s)	CONSTRUCTION COST (CC)	PLANNING DESIGN ADMIN. (C)	TOTAL CAPITAL COST (TC)	ANNUAL OPERATION & MAINTENANCE (OM)	PRESENT VALUE OF O&M[a] (OM_p)	PRESENT VALUE OF POND[a] (P_c)	ANNUAL PAYMENT[b] (A_p)
				1980 dollars						
PEAK SHAVING DRY POND										
"ONSITE"										
Low Density Areas	20	25	30,000	14,860	3,715	18,575	743	7,290	26,610	2,709
High Density Areas	50	50	160,000	34,900	8,725	43,625	1,745	17,130	60,760	6,185
"OFFSITE"										
Low Density Areas	20	150	225,000	41,530	10,380	51,910	2,077	20,390	72,300	7,360
High Density Areas	50	150	500,000	62,405	15.600	78,005	3,120	30,630	108,650	11,060
WET POND AS BMP										
"ONSITE"										
Low Density Areas	20	25	75,000	23,715	5,930	29,645	1,160	11,370	41,020	4,175
High Density Areas	50	50	250,000	48,200	12,050	60,250	2.410	23,660	83,910	8,540
"OFFSITE"										
Low Density Areas	20	150	500,000	62,405	15,600	78,005	3.120	30,630	108,650	11,060
High Density Areas	50	150	775,000	78,030	19,510	97,540	3,902	38,310	135,850	13,830

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[a] 8% discount rate, twenty year project life.

[b] 8% interest rate, twenty year loan.

METHODOLOGY USED TO DERIVE ESTIMATES OF CONTROL COST

Wet and Dry Ponds

The general method used to develop cost estimates of stormwater ponds was to: (1) establish the total cost for individual "unit" ponds, expressed as the present worth of the initial capital investment, plus all subsequent O&M payments; (2) determine the future stormwater storage requirements for each land use scenario, expressed in terms of the total number of "unit" ponds required in the basin; and, (3) multiply the unit cost per pond by the total number of unit ponds required to arrive at the total basin-wide cost.

A complete discussion of the derivation of the number and cost of unit ponds can be found in Technical Paper E in Volume II of this report. A few general comments are made:

- Each of the "unit" ponds used in the costing analysis is equivalent to the ponds utilized in the pollutant removal affectiveness analysis (described in Chapter 6) with respect to drainage area, imperviousness, storage volume and land use.

- Estimated total costs for each unit pond were derived from the functional relationships contained in the Stormwater Pond Cost Study (MWCOG, 1983) and are shown in Table 7.1.

- Estimated future stormwater storage requirements associated with each of the land use planning alternatives were based on the number of acres new development in each of seven major development categories multiplied by an average per acre storage volume requirement for each category. These storage volumes were sufficient to control the two year design storm and were developed from the mimeographs of Detullio and Thomas (1977).

- The approximate number of ponds required in each land use planning alternatives is shown in Table 7.2

Cost Estimates for Agricultural Controls

All of the cost information on agricultural controls were derived from tables supplied in the Little Seneca Watershed Conservation Plan, (SCS, 1982). This PL-566 project, sponsored by the Soil Conservation Service, calls for the application of a wide variety of cropping and livestock management practices to 3,100 acres of agricultural land in the Little Seneca watershed. Some modifications to the SCS cost accounting needed to be made so that the agricultural costs could be directly comparable to those derived for the stormwater ponds. These are detailed in Technical Paper E.

Table 7.2

Future Stormwater Pond Requirements for the Clarksburg Planning Area

ONSITE STORMWATER RETENTION STRATEGY (DRY PONDS)[a]

	NUMBER OF FACILITIES	
LAND USE OPTION	HIGH DENSITY DEVELOPMENT 50 acres/pond @ 100,000 ft^3 Vs	LOW DENSITY DEVELOPMENT 25 acres/pond @ 30,000 ft^3 Vs
Maximum	48	88
Option A	40	97
Option B	39	74
Option C	67	87
Ultimate	71	100

OFFSITE STORMWATER DETENTION STRATEGY (DRY PONDS)[a]

	NUMBER OF FACILITIES	
LAND USE OPTION	HIGH DENSITY DEVELOPMENT 150 acres/pond @ 500,000 ft^3 Vs	LOW DENSITY DEVELOPMENT 150 acres/pond @ 225,000 ft^3 Vs
Maximum	13	11
Option A	12	11
Option B	12	10
Option C	21	10
Ultimate	21	12

ONSITE STORMWATER RETENTION STRATEGY (WET POND)[c]

	NUMBER OF FACILITIES	
LAND USE OPTION	HIGH DENSITY DEVELOPMENT[b] 50 acres/pond @ 250,000 ft^3 Vs	LOW DENSITY DEVELOPMENT 25 acres/pond @ 75,000 ft^3 Vs
Maximum	74	128
Option A	61	123
Option B	60	107
Option C	104	123
Ultimate	102	139

OFFSITE STORMWATER RETENTION STRATEGY (WET POND)[c]

	NUMBER OF FACILITIES	
LAND USE OPTION	HIGH DENSITY DEVELOPMENT 150 acres/pond @ 775,000 ft^3 Vs	LOW DENSITY DEVELOPMENT 150 acres/pond @ 500,000 ft^3 Vs
Maximum	21	16
Option A	16	18
Option B	16	14
Option C	30	14
Ultimate	28	18

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[a] peak shaving dry ponds applied to 70% of new development

[b] extended detention wet pond facilities

[c] normal detention wet pond BMP's applied to 100% of new development

COMPARATIVE COSTS OF BASIN-WIDE CONTROL STRATEGIES

The total basin-wide costs of each land use/control option alternative are summarized in Table 7.3. Several trends are apparent. First, with the exception of agricultural controls, the cost of the same control option increased substantially as the degree of development intensified. For example, the cost of basin-wide application of "on-site" wet ponds in the least developed land use plan (OPTION B) is 2.8 million dollars less than the cost of the most developed plan (ULTIMATE).

Secondly, the basin-wide application of agricultural controls represented a very modest investment when compared to any of the structural stormwater control measures. In most cases, the agricultural BMP program was from three to twenty times less expensive then a basin-wide dry or wet pond strategy.

As far as the relative costs of basin-wide wet and dry ponds are concerned, the general rule of thumb is that the wet pond program would be approximately twice the cost of a dry pond program. This reflects the fact that wet ponds are applied to 100 percent of new development, whereas dry ponds are applied only to 70 percent. When this factor is taken into account, the cost differential between wet and dry ponds is on the order of 28 to 38 percent. The greater cost of wet ponds is primarily due to extra storage volume requirements, and to a lesser extent, to slightly higher O&M expenses.

These did appear to be considerable economies of scale associated with building larger, more centralized "off-site" facilities than the smaller "on-site" ponds. In most cases, aggregate savings approaching 45 to 65 percent can be realized when the larger ponds are constructed. The economies of scale are great enough that an off-site wet pond program can be slightly cheaper than a comparable "on-site" dry pond program.

Several caveats need to be stressed about the magnitude of the economies of scale noted in the off-site ponds. First, an analysis of the costs of 12 off-site ponds recently constructed in Montgomery County (COG, 1983) suggested that the off-site cost advantage can decline sharply if pond drainage areas become much greater than maximum area analyzed in this study (150 acres). Some of the reasons cited for this phenomenon are higher land acquisition or financing costs, more stringent design and safety requirements, greater likelihood for costly re-alignments of sewer lines, roads and other public facilities, and more expensive conveyance system. A second reason for caution is that inherent siting constraints associated with off-site ponds may result in a somewhat lower level of watershed and upstream stream channel protection (personal communication, M-NCPPC, June 1983). Finally, it is probably not realistic to assume that stormwater controls will be applied on a strictly on or off-site basis throughout the watershed. It is more likely that as development proceeds, ponds of many different sizes will be built, depending on local topography site character comparative economics, and the independent decisions of private developers. Therefore, the differential cost of on-site and off-site ponds can be best interpreted as a range in total cost, and that the actual level of stormwater investment will probably occupy some point in the middle.

Table 7.3

Comparative Costs of Basin-wide Control Strategies

	LAND USE PLANNING ALTERNATIVES				
	MAXIMUM	OPTION A	OPTION B	OPTION C	ULTIMATE
	Millions of dollars				
DRY PONDS					
"ONSITE"					
CAPITAL COST	3.7	3.6	3.1	4.6	5.0
AMORTIZED O&M	1.6	1.4	1.2	1.8	2.0
TOTAL COST	5.3	5.0	4.3	6.4	7.0
"OFFSITE"					
CAPITAL COST	1.6	1.7	1.5	2.2	2.3
AMORTIZED O&M	0.6	0.4	0.5	0.8	0.9
TOTAL COST	2.2	2.1	2.0	3.0	3.2
WET PONDS					
"ONSITE"					
CAPITAL COST	8.4	7.4	6.8	9.9	10.3
AMORTIZED O&M	3.1	2.7	2.6	3.9	4.0
TOTAL COST	11.4	10.1	9.4	13.8	14.3
"OFFSITE"					
CAPITAL COST	3.3	3.0	2.7	4.0	4.2
AMORTIZED O&M	1.3	1.1	1.0	1.6	1.6
TOTAL COST	4.6	4.1	3.7	5.6	5.8
AGRICULTURAL BMP's					
CAPITAL COST	0.26	0.37	0.40	0.33	0.04
AMORTIZED O&M	0.16	0.23	0.26	0.21	0.03
TOTAL COST	0.42	0.60	0.66	0.54	0.07
MIXED BMP'S[1]					
CAPITAL COST	3.6	3.4	3.1	4.3	4.2
AMORTIZED O&M	1.4	1.3	1.3	1.8	1.7
TOTAL COST	5.0	4.7	4.4	6.1	5.9

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[1] Combined agricultural controls and offsite wet ponds.

COMPARATIVE COSTS OF CONTROLS: PER PROPERTY UNIT

Another way to analyze the costs of control strategies is to relate them to typical costs per property units. For dry and wet stormwater facilities, these costs can be translated into the cost per new residential dwelling unit, or new commercial acre. In the case of agricultural controls, they can be defined as the cost per treated acre. Tables 7.4 and 7.5 depict the total cost and corresponding annual payment required for each control strategy.

In terms of the estimated annual payment needed to finance a given control strategy, the residential cost ranges from $14 to $22/DU/year for on-site dry and wet ponds, respectively (Table 7.4). In general, the annual payment for a specific residential land use is closely related to the density of development; i.e., as more dwelling units are packed into each acre, the marginal cost for each dwelling unit declines. A recent stormwater cost study demonstrated that the variation residential stormwater costs can range from $5/DU/year for high-rise residential development to nearly $50/DU/year for large lot single family development (MWCOG, 1983), (Figure 7.1).

As can be seen in Table 7.5, the estimated long-term cost of dry or wet residential stormwater controls is rather moderate in comparison to the costs of stormwater controls for new commercial areas. For example, the total cost of on-site wet pond for residential areas comes to approximately $219/new dwelling unit, while the same controls cost $3,186/commercial acre. This cost differential can be principally attributed to the greater runoff storage requirements necessary for control of the much higher degree of the impervious typically associated with commercial areas.

Estimated annual payments for commercial acreage ranged $236/acre/year for on-site dry ponds to $325/acre/year for on-site wet ponds. By way of contrast, the average annual payment required to install and maintain agricultural best management practices within the basin is only $23/acre/year.

Table 7.4 Estimated Annual Payment for Control Strategies on a Property Unit Basis

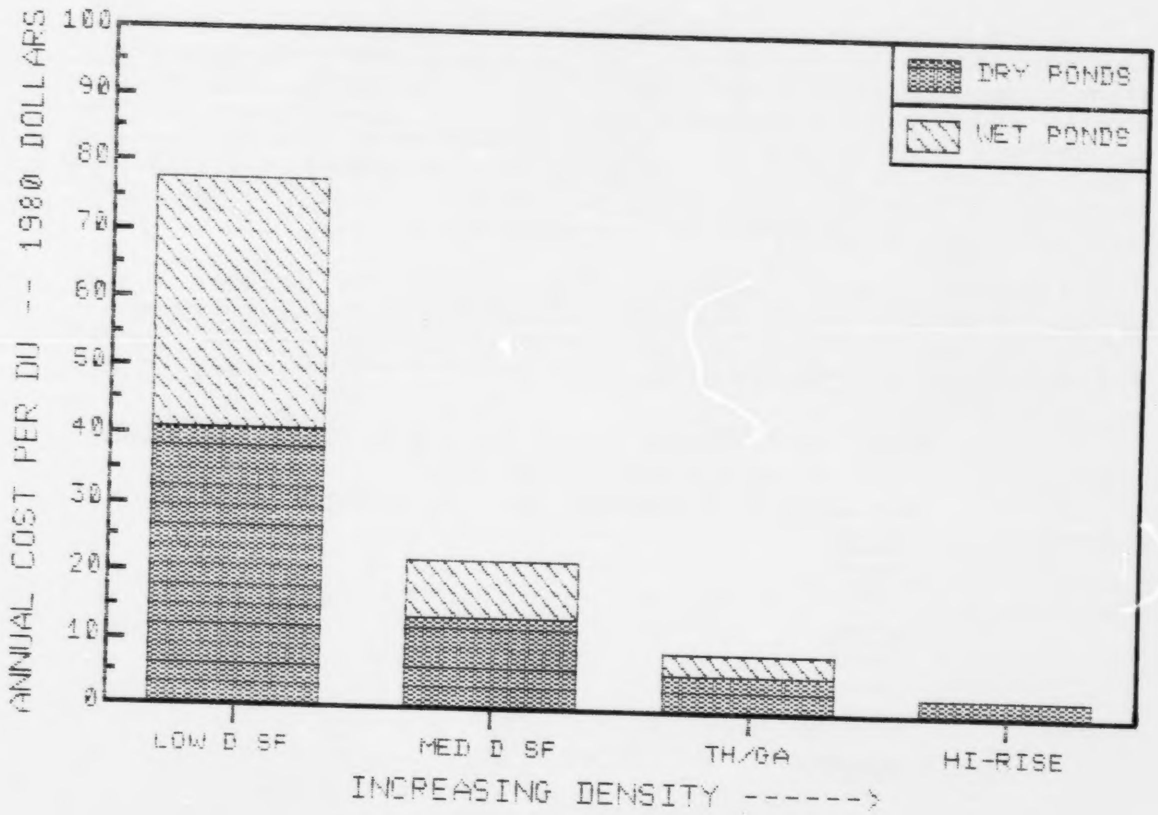
CONTROL STRATEGY	$/DWELLING UNIT/YR	$/COMMERCIAL ACRE/YR	$/TREATED ACRE/YR
DRY PONDS			
"ONSITE"	14	236	-
"OFFSITE"	6	125	-
WET PONDS			
"ONSITE"	22	325	-
"OFFSITE"	8	154	-
AGRICULTURAL CONTROLS	-	-	23
MIXED BMP's	8-22	154-325	23

Table 7.5 Estimated Long Term Cost of Control Strategies Per Property Unit

CONTROL STRATEGY	$/DWELLING UNIT	$/COMMERCIAL AC.	$/TREATED ACRE
DRY PONDS			
"ONSITE"	138	2316	-
"OFFSITE"	60	1229	-
WET PONDS			
"ONSITE"	219	3186	-
"OFFSITE"	81	1508	-
AGRICULTURAL CONTROLS	-	-	230
MIXED BMP's	variable	variable	230

Figure 7.1

Variation in Residential Stormwater Costs



COST-EFFECTIVENESS ANALYSIS

The final level of analysis involved the direct comparison of the total basin-wide cost of a particular land use planning/control strategy combination with its relative effectiveness (as determined by its numerical ranking in the relative overall water quality index presented in Chapter 6. These results are presented in graphical form in Figure 7.2. The index of relative water quality is on the x-axis, and the control cost is displayed on the y-axis. Each point represents the combination of a unique land use planning alternative and control strategy. Dashed lines connect different control strategies with the same land use planning alternatives. As such, each line represents a rudimentary cost curve for each land use planning alternative (Note: the costs dry pond (SM), wet pond (WP) and mixed BMP (MX) scenario all reflect the use of off-site ponds only).

The cost-effectiveness comparisons have several interesting features. In general, the cost curves form a consistent concentric pattern, with the most developed (U) or intensively concentrated (C) development scenarios forming the outside boundaries, while the least intensive development scenarios (A and B) establishing the inner boundaries. The outer curves represent the greatest control cost and the lower water quality levels, while the inner curves have the smallest control cost and the higher overall water quality. The principal conclusion, is that land use planning alternatives which emphasize conservation of open space and are oriented to lower density development, when combined with wet ponds and/or agricultural controls can be both a relatively inexpensive and extremely effective control program. It is also evident that conventional dry stormwater management ponds do not result in significant changes in overall water quality (i.e., all of the points lie on the impairment side of the water quality index). Coupled with their sizeable cost, dry ponds do not appear to be as attractive a nonpoint source control investment as wet ponds, which confer significant improvements in water quality at a modest increase in marginal cost.

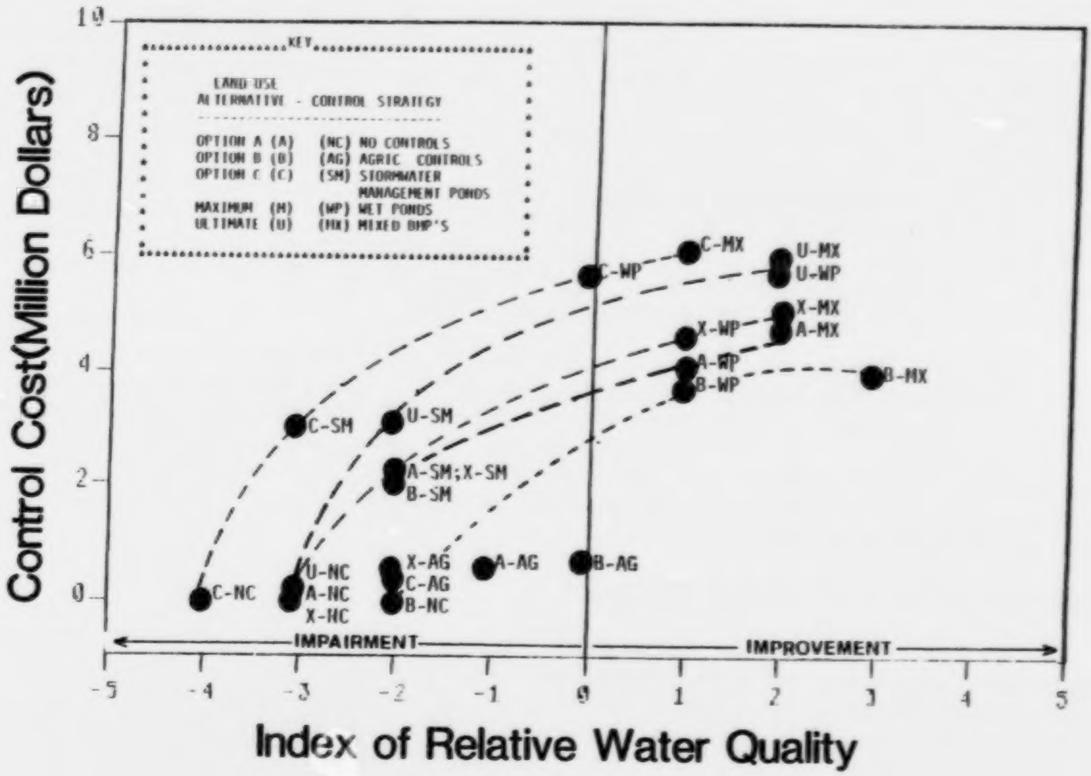
The control strategy which yielded the greatest improvement in overall water quality at the smallest increment of total cost was the agricultural BMP program. However, in most cases the agricultural BMP program, by itself, was not sufficient to either maintain or improve overall water quality conditions. Nonetheless, the full implementation of the agricultural BMP program would be the most cost-effective first step in a comprehensive watershed control program.

Economic Benefits of Control Strategies

The economic benefits achieved by a given watershed control strategy have been extremely difficult to express in quantitative terms. Some of the conceivable benefits that could arise from an effective basin-wide control program might be:

- Cost savings in the form of reduced dredging and disposal costs in the forebays and main reservoir of Little Seneca Lake.
- Protection of property and human life from flooding.
- Long-term savings related to the conservation of highly productive agricultural soils.

Figure 7.2 Cost-Effectiveness of Control Strategies

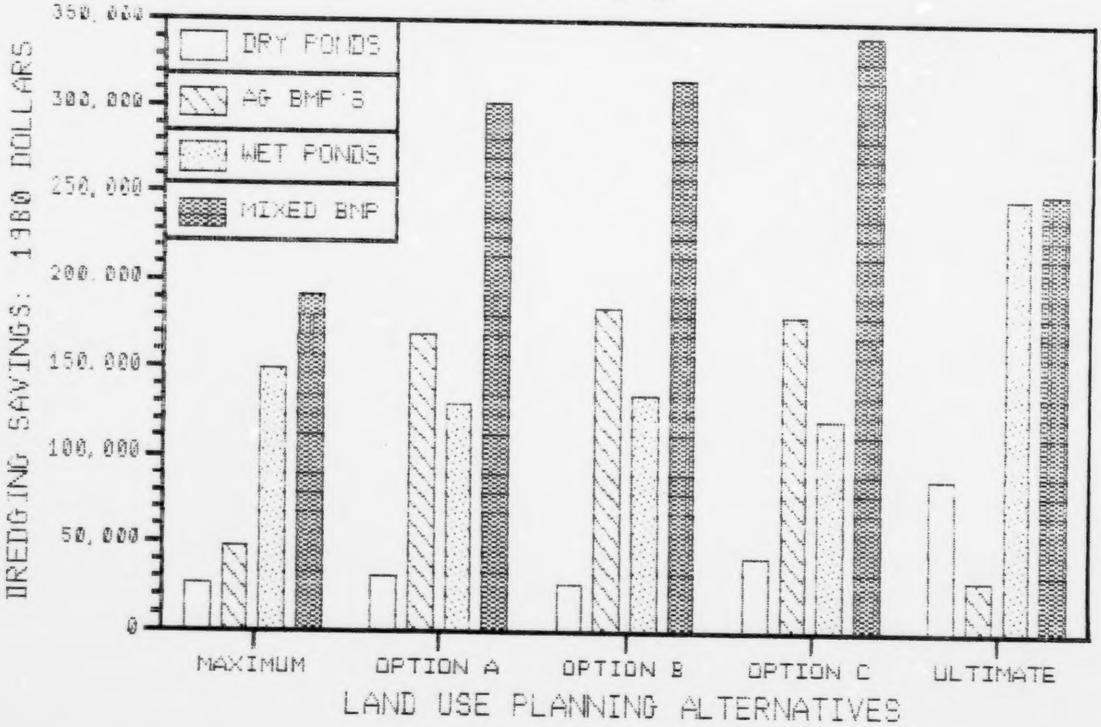


- Recreational benefits arising from the continued maintenance of a recreational trout fishery in the tributary streams and the potential warm water fishery of the lake itself.

- Aesthetic benefits achieved by reducing the stormwater impacts to the habitat and channels of tributary streams; and by reducing the potential for diminished water clarity within Little Seneca Lake. These rather intangible benefits take on greater importance because of the planned development of stream valley and regional parks within the basin.

While this list is not considered to be exhaustive, it does provide some indication of the overall value of an effective control program. In this study, it was only possible to assign an economic value to one of these benefits -- savings in sediment dredging costs. These are presented in Figure 7.3, which shows the present worth of dredging/disposal cost savings attributable to each control strategy, discounted over the assumed life of the controls. These estimates were prepared using the methodology used in Black and Veatch, (1979). As can be seen from the figure, the application of mixed BMPs saves between $190,000-$330,000 in dredging costs, over 20 years. Agricultural controls save approximately $150,000-$175,000 in dredging costs. (in those land use plans in which agricultural is retained in reasonable quantity) Wet ponds can save from $129,000-$240,000. A dry pond control program, on the other hand, would save only $25,000-$80,000. It should be noted that the previous cost estimates pertain to the sediment forebays only, since dredging of the reservoir was considered to be too expensive to implement. Thus, significant additional benefits in terms of protecting reservoir storage capacity would also be realized for many control strategies.

Figure 7.3
Economic Benefits of Controls:
Cost Savings Relating to Dredging



Chapter Eight
FEATURES OF AN EFFECTIVE NONPOINT SOURCE CONTROL STRATEGY

FEATURES OF AN EFFECTIVE NONPOINT SOURCE STRATEGY

The results of the water quality monitoring and modeling activities conducted as part of this study have several important implications relating to watershed management within Seneca Creek. First the existing water quality conditions in Seneca Creek and its tributaries represent a substantial change from the PRISTINE (reforested) condition simulated to represent the watershed prior to human settlement. The effects of man's agricultural practices, and more recently, suburban development, have induced significant changes in quality of stream waters and habitat. The long-term effects of runoff from increased watershed development appear to have changed the composition and reduced the diversity of the fish community noted in the historical record.

The cumulative effect of man's activities within the watershed is also reflected in the snapshots of water quality conditions obtained in recent monitoring efforts. These data indicate that Seneca Creek currently experiences high suspended sediment and bacterial concentrations in three out of every four days. Elevated levels of nutrients and trace metals are also a common occurrence in the stream. Taken together, the monitoring data provide evidence that, at varying points and frequencies, some of the beneficial uses of the stream are currently being imparied.

A major conclusion emerging from the watershed modeling efforts is that Seneca Creek is likely to undergo further deterioration in the future, if anticipated growth occurs without any kind of stormwater and nonpoint source controls. Much of the projected deterioration involves changes in the physical nature of the stream, such as increased flooding, streambank erosion and suspended sediment levels. Higher nonpoint loading levels are also predicted for the watershed in the future. These nutrient loadings are believed to be sufficiently great to induce eutrophic conditions in the various water impoundments within the basin.

Consideration of both present and future water quality conditions suggest that a comprehensive stormwater and nonpoint sources management control strategy will be necessary to reduce further impairment and/or improve instream habitat and aquatic life in Seneca Creek and its tributaries, and to maintain acceptable levels of of water quality in Little Seneca Lake and other impoundments.

The selection and implementation of a effective basin-wide control program necessitates consideration of a wide variety of technical, economic and institutional factors. This study has identified several different combinations of land use planning and control measures which were projected to be effective in mitigating the impacts of future development, and in some cases, improve on existing conditions. Therefore, there are a diversity of possible approaches which local planners and decision-makers can implement to develop an effective program of stormwater and nonpoint source controls within the basin. Several general considerations, however, should be incorporated into the fabric of any watershed plan, and these are outlined below:

Characteristics of an Effective Nonpoint Source Control Strategy

Targeting Resources

A primary requirement of any control strategy is that it be oriented toward achieving specific objectives. One such objective is to target management resources towards controlling the water quality constituents which exert the greatest stress on the stream or impair a desired use of the stream. In this respect, this study has identified the control of sediments and urban stormwaters as being a primary concern. Control of nutrients is also warranted in sub-basins draining into impoundments, such as Little Seneca Lake.

A second objective is to target management resources specific areas within the watershed which are likely to be the most severely impacted, or contain unique aquatic resources that are more sensitive to impacts. Three such areas were identified in this study.

1. The Little Seneca Watershed. This twenty square mile watershed merits protection for several reasons. Model simulations indicate that this area will experience greater adverse impacts than any other portion of the entire Seneca Creek watershed, particularly with respect to stream habitat. The tributary streams are the only Class IV waters within the entire basin, and also contain the most diverse fish community. These simulations also indicate that nonpoint loads generated in this sub-watershed could have serious adverse effects on water quality within the Little Seneca emergency water supply reservoir, which is presently under construction.

2. Headwater Streams in Urbanizing Areas. There are over 225 miles of perrenial streams within the Seneca Creek watershed (M-NCPPC, 1977). Most of these streams are small, shallow and fast moving, such as Long Draught Branch, Whetstone Run, Magruder Branch, Gunners Branch, and Backlodge Branch. Because of their small size, these streams are especially susceptible to the impacts of development, particularly habitat destruction brought about by urbanization. Many of these smaller streams have unique fish communities and serve as valuable wildlife habitat. Model simulations indicate that the most heavily impacted headwater streams will be those located near the corridor cities of Damascus, Clarksburg, Germantown, and Gaithersburg.

3. Basin Impoundments. Observed nutrient concentrations in both urban and agricultural runoff are sufficient to induce eutrophic conditions in standing waters. Therefore, it is likely that many of the lakes, reservoirs, and ponds within the watershed may be adversely affected by nutrient enrichment. Some of these potentially troublesome areas are Little Seneca, Churchill, Whetstone, Walker and Long Draught lakes.

Pre-Development Land Use Planning Measures

The extreme sensitivity of Seneca Creek water quality and quantity to increased levels of development, and particularly basin imperviousness, has been repeatedly demonstrated. Model simulations indicate that, from the standpoint of water quality, modifications to the adopted ULTIMATE master plan in the Clarksburg Planning Area could significantly reduce potentially adverse effects on tributary streams and the water quality of Little Seneca Lake (which had not been proposed at the time the original 1975 Master Plan had been prepared). Several of the land use options under study by M-NCPPC exhibited excellent potential for reducing these adverse impacts. In general, those land use options which emphasized lower density zoning and conservation of open space had the most pronounced effect.

Other land use planning measures could be undertaken which substantial effects on reducing future impacts in the watershed. These measures fall into two general categories: Protection and/or Conservation of Open Space and planning measures oriented toward reducing the degree of imperviousness in developed areas.

Several existing County programs specifically deal with protecting open space. These include the stream valley and regional park land acquisition program, the agricultural preservation plan and the floodplain protection program. Continued application of these successful programs in the Seneca watershed is actively encouraged.

Measures which reduce the degree of effective imperviousness associated with future developmnt are normally incorporated into the site plan review process. These pre-development measures can include the use of cluster development in place of conventional development, siting arrangements which disconnect impervious areas and maximize the travel distance between these areas and receiving waters, and finally, careful planning to ensure that as many of the existing trees, shrub and cover on undeveloped lots are retained.

Selection of Stormwater Control Structures with High Pollutant Removal Capability

The Montgomery County stormwater control ordinance has been a most effective model of local environmental protection laws. Since the adoption of the ordinance in the early 1970s over 1,400 structures are estimated to have been installed in the County. In 1982, nearly 60 stormwater structures were either installed or approved, which collectively served between 1.1 to 2.3 square miles of new development (MWCOG, 1983). The great majority of these structures were conventional "dry" stormwater ponds; however, an increasing trend toward its use of wet ponds was noted. These multi-purpose structures presently account for about 10 percent of all new ponds installed.

The Stormwater Control Ordinance is clearly one of the most useful institutional mechanisms available to local planners to deal with urban runoff. It is strongly recommended that the County should actively encourage, through its planning and review process, the utilization of stormwater control structures which have high pollutant removal capabilities. This study has demonstrated that "wet" stormwater pond designs are superior to their dry pond counterparts with respect to pollutant removal. Recent studies by the Urban Wildlife Institute (1983) have shown that wet ponds also have greater benefits in terms of general aesthetics, recreation, fish and wildlife habitat, and landscape value, than do dry ponds. A survey of 360 residents of Columbia, Md., conducted by the Urban Wildlife Institute (Table 8.1) indicates that residents prefer wet ponds over dry ponds by a 4 to 1 margin. Three fourths of the residents felt that wet ponds added to the real estate value of their homes, and also expressed a willingness to pay more for a home situated near a wet stormwater pond. Properly designed and maintained, wet stormwater ponds can be a valuable landscape feature.

Other urban best management practices also have significant pollutant removal capabilities, as well. The selection of wet ponds to be incorporated into the detailed control effectiveness modeling should not be construed to eliminate the application of other promising urban BMPs. Table 8.2 gives a

Table 8.1

CITIZEN ATTITUDES TOWARD STORMWATER BASINS

94% of residents felt it is desirable to design and manage stormwater basins for fish and wildlife

Residents prefered wet ponds over dry ponds by a 4 to 1 margin

75% of residents felt wet ponds add to the real estate value of their homes

73% expressed a willingness to pay more for home situated near a wet pond

Residents perceived benefits of ponds

	Wet (%)	Dry (%)
Wildlife attraction	65	22
Aesthetic appeal	58	22
Recreation opportunity	40	5
Fishing	29	0

Source: National Institute for Urban Wildlife Resident Attitude Survey, Columbia, MD.
360 Respondents

Table 8.2

Assessment of Urban BMP's in Washington NURP Study

Dry Ponds

- Not an effective best management practice
- Low (<20%) or negative removal efficiencies for most parameters in most storms
- Mediocre performance due to:
  - — Reliance on physical setting alone
  - — Brief residence time
  - — Resuspension of deposited materials
  - — Scour/erosion of pond bed
- Design modifications might improve efficiencies considerably

Extended Detention Ponds

- Serve as a moderately effective BMP
- Typically have high efficiencies for removal of particulates
- Removal of soluble nutrient forms is minimal
- Did not experience scour/resuspension problems because pond had:
  - — Paved channel
  - — Established vegetation
  - — High length/width ratio

Wet Ponds

- Moderate to high efficiencies for particulates
- High efficiencies for soluble nutrient forms
- Substantial fluctuations in removal rates for individual storms
- Rate increases with storm size for sediment associated parameters
- Mechanisms for pollutant removal include:
  - — Physical settling
  - — Chemical flocculation
  - — Biological uptake

Grassed Swales

- Very limited value as a BMP in sites compared
- No statistically significant improvement in runoff quality over curb and gutter systems was demonstrated (synoptic storms)
- In some cases, median loading rates were higher in grassed swales
- Elevated zinc levels due to acid precipitation effect on driveway culverts
- Effectiveness limited because contact time < infilt. rate
- May still be useful on sandy coastal plain soils

Porous Pavement

- Very effective BMP for both water quality and quantity
- Extend duration of storm runoff (up to 24 hours) and dramatically reduce peak flows
- Extremely high removals of particulates and trace metals
- Removal of nutrients also high, but only moderate for soluble forms
- Chief removal mechanisms
  - — Rapid infiltration
  - — Adsorption to soil

Infiltration Pits

- Variable effectiveness as BMP
- Moderate removal of particulate materials
- Minimal to negative removal for nutrients
- Efficiency is probably related to length of contact time in pit

brief description on the overall evaluation as to the effectiveness of the six kinds of urban BMPs evaluated as part of COG's overall NURP project. As can be seen, several of these BMPs have significant potential to remove sediments, nutrients and trace metals borne in urban runoff. These BMPs include porous pavement, extended detention dry ponds and infiltration controls. The high pollutant removal capability noted in these controls are especially encouraging in that they allow for a diverse approach to urban runoff control, suited to the unique characteristics of each development site.

Design of stormwater structures is a crucial step in controlling urban runoff. In the past, design of stormwater structures has focused rather exclusively on control of low frequency/high peak storm events. Added emphasis on designing BMPs which enhance nonpoint pollutant removal capabilities and reduce long term maintenance problems will be a necessary component of local stormwater management programs.

Use of Agricultural Controls

The detailed modeling work conducted in the Clarksburg Planning Area demonstrated the cost-effectiveness of applying agricultural best management practices as a first step in a comprehensive watershed management program. Therefore, the continued implementation of the Little Seneca watershed conservation plan should be actively supported. Full cooperation of other farmers in the basin in long term conservation agreements with the Montgomery County Soil Conservation Districts also should be aggressively pursued.

Unfortunately, participation by farmers in these programs has been rather erratic over the years (e.g., it appears, as of this writing, that participation in the Little Seneca watershed conservation plan has been extremely limited so far). One possible approach to increase participation might be to directly condition landowner eligibility for tax benefits under the County's agricultural preservation program to evidence of participation in a long term conservation agreement with the local soil conservation district.

Full Implementation of Controls

The projected effectiveness of the control measures cited in this study is predicated on two important factors: full application of controls to all new development and continued maintenance of the controls over their useful life.

The importance of each of these factors cannot be over-stressed. Thus, an effective basin-wide control program will require full implemetation and continuing maintenance of controls.

Assumption of Maintenance

Since most of the onsite and jointly shared stormwater facilities required under the Montgomery County Stormwater Law are built and operated by private developers, little control is currently exercised over pond maintenance. Given the relatively high cost of operation and maintenance (approaching one third of total construction cost) there may not be adequate incentives for private developers to keep their ponds operating efficiently and safely. Maintenance of stormwater ponds is an integral feature of any strategy if consistently efficient pollutant removal and stormwater control is to be achieved, and if public safety and aesthetics are to be protected.

Therefore, it is recommended that the County either take over the responsibility for stormwater pond O&M or initiate a regular inspection and enforcement program to assure that standard SWM controls continue to operate effectively throughout their full design life.

Water Quality Monitoring

Water quality monitoring is an important feature of any watershed control program. Monitoring would enable planners to: (1) gauge the progress of a basin-wide control program; (2) assess long term trends in water quality; (3) identify problem areas in the watershed; and, (4) allow for possible reverification of the Seneca Creek Model. It is recommended that a sampling program be reinstituted in the watershed, and that it be specifically designed to incorporate collection of storm integrated samples at a few locations in the watershed (such as at the tributaries to Little Seneca Lake) and regular grab samples elsewhere. It is further recommended that this sampling have an additional biological aspect, including occasional analyses of trace metal residues in fish tissues.

As a first priority, this sampling program should be capable of tracking pollutant inputs and outputs three Little Seneca Lake, as well as investigating water quality conditions within the Lake itself.

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